ASSESSMENT OF BIOMASS VARIABILITY, BIOMASS CONVERSION, AND ETHANOL USE

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EXECUTIVE SUMMARY

The primary objective of this effort has been to characterize all aspects of biomass ethanol for the years 1995-2030. To accurately analyze and depict these technologies, the biomass ethanol characterization has been segmented into three parts, namely:

- Biomass Feedstock Supply;
- Biomass-to-Ethanol Conversion; and
- Ethanol Use.

Throughout this effort, the study team gathered all reasonably-accessible and available data on biomass production, harvesting, collection, storage, conversion and emissions. This information was, in turn, used to develop two inter-linked models: the Biomass Feedstock Variability Model (BFVM) and the Biomass-to-Ethanol Variability Model (BTEVM). The first model provides projections concerning feedstock availability, while the second model projects annual ethanol throughputs, based on the projected amounts of feedstock available.

The BFVM allows for regional and national analyses, based on either a geographic area, a biomass feedstock class, or a combination of both for the modeling time frame. The BFVM segments the United States into five regions, which consist of the Northeast (NE); a combined Southeast and South Central region (SE/SC); a North Central (NC) region; the Pacific Coast (PC); and the Rocky Mountains (RM) region. This model restricts the analysis to four major biomass feedstock classes, namely: Short Rotation Woody Crops (SRWC); Herbaceous Energy Crops (HEC); Agricultural Residues (AR); and Municipal Solid Wastes (MSW). Within SRWC, HEC, and AR, the model accounts for further divisions (such as switchgrass for HECs, hybrid poplars for SRWC, and corn stover for AR) within each feedstock class. The distribution of biomass feedstock classes is region-specific. That is, a specific crop derived from each region is dependent on that region's soil type, land class, landscape, climate, etc. The BFVM also addresses the physical and chemical characteristics of each feedstock class, as well as the emissions related to production, harvesting/collection, sorting/separation, transportation and storage.

The BTEVM addresses the conversion of the above-mentioned feedstock into ethanol. Given the composition and the amounts of the feedstock, and making assumptions about plant capacity and design parameters, the BTEVM computes: the expected amount of ethanol product (and by-products); the required amounts of input chemicals and utilities; the levels of emissions and pollutants released to air, water and land; and the wholesale price of the ethanol product for a given year. Based on various assumptions about each region's resource base and availability of each feedstock (in terms of time), the BFVM projects the following amounts of feedstock to be available for conversion to ethanol in million tons per year:

	SRWC	HEC	MSW	AR
1995	0	0	11	24
2000	50	57	46	48
2010	84	184	110	48
2020	109	326	124	48
2030	134	596	140	48

Based on the above figure and future efficiency gains, the second model (BTEVM) projects the following levels of ethanol throughput per year (in million gallons and quad equivalent).

	SRWC	HEC	MSW	AR	Total Gallons	Total Quads
1995	0	0	846	1,260	2,105	0.16
2000	4,625	4,530	3,525	2,546	15,226	1.16
2010	7,896	15,274	8,473	2,580	34,223	2.60
2020	10,544	28,186	9,767	2,617	51,114	3.88
2030	13,259	53,119	11,248	2,650	80,276	6.10

I. FEEDSTOCK CHARACTERIZATION

1. Biomass Feedstock Variability Model (BFVM) Overview

The BFVM is a complex and robust model which allows for regional and national analyses, based on either a geographic area or biomass feedstock class, or a combination of both, for each of the six years analyzed (1995 as the base year, 2000, 2005, 2010, 2020 and 2030).

The wide array of analyses capable of being performed by the BFVM includes: feedstock blend composition, delivered costs of various biomass feedstocks, total producible tonnage of feedstocks and/or the timeliness of producibility, and the emissions related to production and transportation of a given quantity of feedstock. This flexibility has been provided to allow for one or several of the previously-mentioned variables to be manipulated and results analyzed, without having to modify the structure and/or logic of the model.

Upon review of primary data sources, it was found that several methods have been used (not always consistently) to segment the U.S. into regions. As shown in Figure I-1, for this effort, the continental U.S. has been segmented into the following five regions: the Pacific Coast (PC); Rocky Mountains (RM); North Central (NC); Northeast (NE); and a combined Southeast/South Central (SE/SC) region. This combination was necessary due to the lack of detailed and consistent data on types of biomass possible, production potential, and related emissions for the South Central area. This five-region approach is consistent with the methodology used by Graham.[1] As such, the potential biomass production figures generated by Graham's analysis can be readily incorporated into the BFVM. Data used from other sources were adjusted where necessary.

Information presented below will be shown primarily at an aggregated national level. Specific regional information and detail BFVM content can be reviewed in Appendix A.

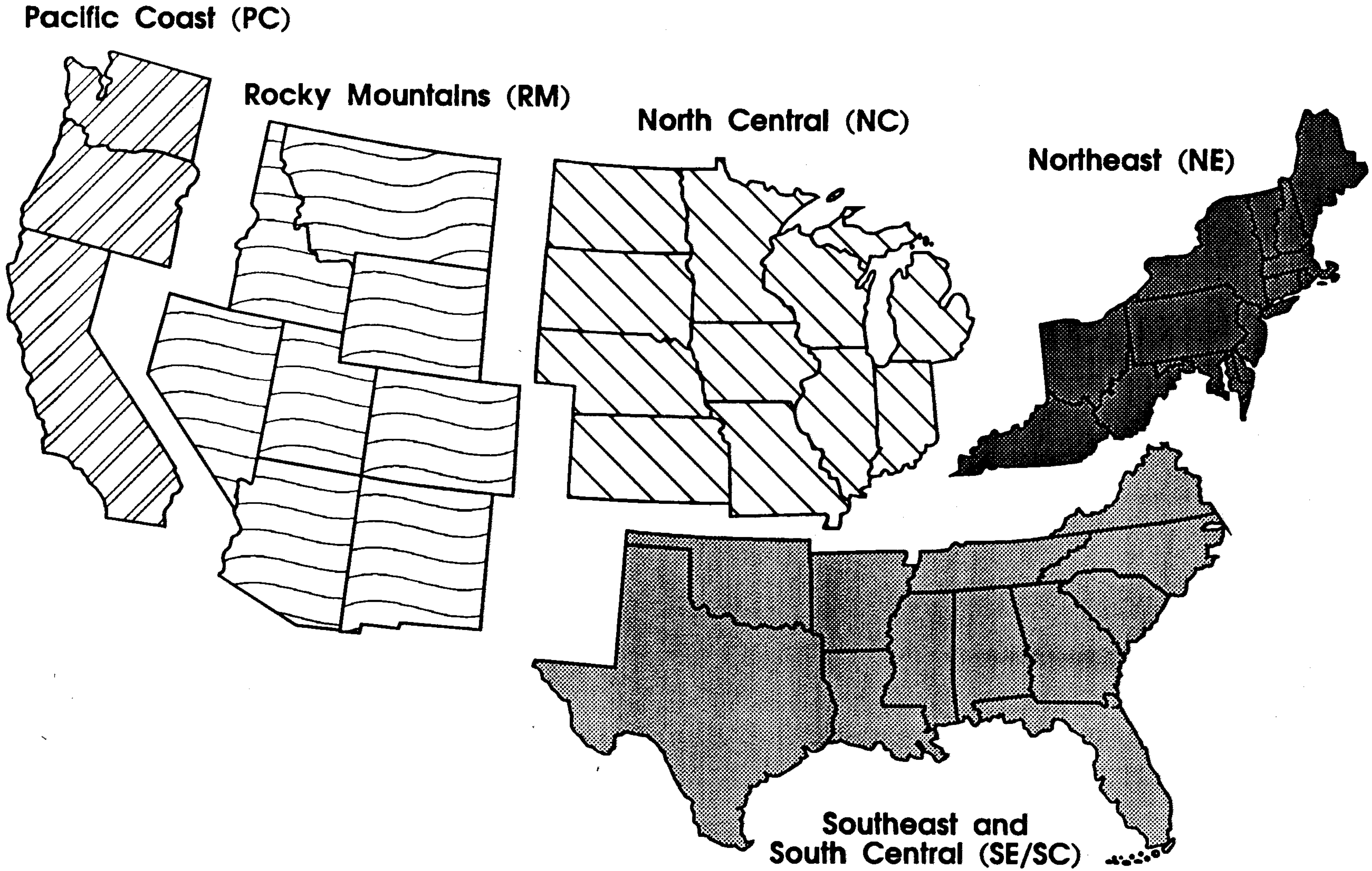
2. Feedstock Selection

It is generally agreed that there are four main biomass feedstock classes relevant to the production of biomass ethanol. These are:

a). Short Rotation Woody Crops (SRWC)
b). Herbaceous Energy Crops (HECs)
c). Agricultural Residues (ARs)
d). Municipal Solid Waste (MSW)

Each of these biomass feedstock classes are somewhat distinct. Short Rotation Woody Crops (SRWCs) are specially-developed tree crops which grow to harvesting size at an average of approximately six years. Because of their multiple year growing cycles, these crops will most likely be developed in stages so that six years after the initial sowing, one-sixth of the plantings can be harvested each year. This practice will ensure that SRWCs are available to an ethanol conversion facility annually.

FIGURE I-1
REGIONS USED BY THE BIOMASS FEEDSTOCK VARIABILITY MODEL



Herbaceous energy crops (HECs) are non-woody crops, which have much shorter growing cycles than SRWCs. HECs are expected to play a large future role in any biomass-ethanol industry. The HEC categories can be further be broken into perennials and annuals. Perennial crops are those that can be grown and harvested more than once per year. The annuals take a full year from planting to harvesting. Research indicates that initially it will require two to three years to establish these crops.

Agricultural residues (ARs) are the remaining portion of conventional crops left in the field after regular harvesting. ARs are a near-term readily available biomass feedstock.

Municipal solid waste (MSW) is generated mostly in urban areas with some of the MSW being transported to rural landfills. The cellulosic fractions of the MSW are a potential feedstock source for the biomass ethanol conversion process.

3. Feedstock Composition

SRWCs, HECs and ARs can be further broken down into the types of crops that are assumed to make up these categories. This distinction is important since the specific crops derived from each region of the United States will depend on several variables such as soil type, land class, land slope, drainage, climate, etc. In addition, as discussed below, each individual crop may have distinctive physical characteristics that may impact the biomass ethanol conversion processes discussed in Section II of this report. Table I-1 illustrates, by region, the assumptions made as to what types of crops make up each category.

Data for the SRWCs and HECs are consistent with underlying Total Fuel Cycle Analysis (TFCA) assumptions.[2] However, some modifications to the TFCA assumptions were required. For example, the TFCA was based on five site-specific locations in the United States. For the BFVM, it has been further assumed that these site-specific data are representative of the entire region. For example, TFCA site-specific data for Peoria, Ilinois are assumed to be representative of the whole North Central Region.

As mentioned in the TFCA, the selected (SRWC and HEC) feedstocks are not necessarily the optimal combination of feedstocks or represent the entire range of possible energy crops for a region. The main objective was to identify and use crops that would assure a continuous year-round supply of biomass feedstocks to a conversion facility. One other main TFCA assumption was that production operations were assumed to be approximately the same across all locations for each of the two biomass classes studied and soil types. According to the Oak Ridge National Laboratory, this is not an accurate assumption but was necessary due to a lack of comprehensive information.

Agricultural residues information was derived from Tyson (1991)[3] and Meridian Corporation (1992)[4] primary data sources.

Municipal solid waste composition information was derived from a recent U.S. Environmental Protection Agency report.[5]

TABLE I-1
FEEDSTOCK BLEND CHARACTERISTICS

	REGION =	NE	SE/SC	NC	RM	PC
SRWCs		100%	100%	100%	0%	100%
	Hybrid Poplar	60%	0%	50%	0%	0%
	Willow	20%	0%	0%	0%	0%
	Black Locust	20%	10%	20%	0%	0%
	Sweetgum	0%	50%	0%	0%	0%
	Sycamore	0%	40%	0%	0%	0%
	Silver Maple	0%	0%	30%	0%	0%
	Hybrid Cottonwood	0%	0%	0%	0%	80%
	Red Alder	0%	0%	0%	0%	20%
HECs		100%	100%	100%	0%	100%
	Switchgrass	50%	82%	57%	0%	100%
	Reed Canarygrass	50%	0%	19%	0%	0%
	Wheatgrass	0%	0%	0%	0%	0%
	Energy Cane	0%	19%	0%	0%	0%
	Sorghum	0%	0%	24%	0%	0%
MSW		100%	100%	100%	100%	100%
ARs		100%	100%	100%	100%	100%
	Corn	81%	24%	76%	12%	7%
	Sorghum	0%	4%	2%	6%	0%
	Wheat	19%	62%	22%	81%	93%
	Sugar Cane	0%	10%	0%	0%	0%

Using the specific crop distributions for each region, it is assumed that no matter how many quads or tons (and aggregate composition) are produced of a particular biomass feedstock class from a particular region, the proportions within each class will remain the same. For example, as will be shown later, it was found that the NE region contains 10.94% of the total resource base for HECs. Therefore, no matter how many quads of HEC output is assumed nationally (up to the resource base maximum), BFVM assigns 10.94% of the HECs quads to be produced from the NE.

4. Feedstock Physical Characteristics

The three most important feedstock physical characteristics are the moisture content per dry ton, the energy content per dry ton, and the physical composition of the feedstocks on an individual and regional basis.

Total tonnage yield depicted in the BFVM is assumed to be on a dry ton basis for all feedstocks. This coincides with other reports, and their respective assumptions, including projections of yield and costs. However, even the dry ton assumptions are not consistent regarding moisture content. Table I-2 depicts the moisture and energy content assumptions used in the BFVM for each biomass class and region.

Physical characteristics data used in the model are derived from the percentage distribution of each individual crop making up the feedstock composition for a particular biomass feedstock class and region. Table I-3 illustrates the average compositions for the four biomass classes in each region. As shown in Table I-3, regional physical characteristics are different (except for MSW), because of the varying percentages and types of individual crops that contribute to the regional aggregate composition.

Of the categories shown in Table I-3, the two most important categories for the production of ethanol are cellulose and hemicellulose. These two categories are the portion of the feedstock that will be converted to sugars and then to ethanol. Other portions of the feedstock are also important as they can contribute to some of the process economics (i.e., unused fractions being used as boiler fuel to produce electricity).

5. Feedstock Production

Several primary data sources were required in order to define the potential resource base for each biomass class. Once these were established, certain assumptions were made as to the year and volume these resources would be available to the biomass ethanol conversion facilities. Below is an overview of the biomass resource potential for each biomass class. The overview is followed by BFVM projections of the distribution of biomass production among regions and the actual production assumptions used in the BFVM.

TABLE I-2
BIOMASS FEEDSTOCK PHYSICAL CHARACTERISTICS

REGION =	NE	SE/SC	NC	RM	PC
SRWCs					
Moisture Content (%)	25.0%	25.0%	25.0%	25.0%	25.0%
Energy Content (Btu/lb)	8500	8500	8500	8500	8500
HECs					
Perennial Crops					
Moisture Content (%)	25.0%	25.0%	25.0%	25.0%	25.0%
Energy Content (Btu/lb)	7500	7500	7500	7500	7500
Annual Crops					
Moisture Content (%)	233.0%	233.0%	233.0%	233.0%	233.0%
Energy Content (Btu/lb)	7500	7500	7500	7500	7500
MSW					
Moisture Content (%)	25.0%	25.0%	25.0%	25.0%	25.0%
Energy Content (Btu/lb)	8000	8000	8000	8000	8000
ARs					
Moisture Content (%)	25.0%	25.0%	25.0%	25.0%	25.0%
Energy Content (Btu/lb)	7000	7000	7000	7000	7000

TABLE I-3
AVERAGE CELLULOSIC COMPOSITION BY BIOMASS CLASS AND REGION (BASE ASSUMPTION)

		NE	SE/SC	NC	RM	PC
SRWC	(%wt)					
cellulose		47.66	45.64	47.79	0.00	48.78
hemi-cellulose		17.69	25.27	18.39	0.00	18.78
lignin		24.74	23.37	24.36	0.00	26.24
ash		0.84	0.47	0.95	0.00	1.63
NS carbohydrates		4.83	3.52	5.06	0.00	3.20
C. protein		0.50	0.50	0.50	0.00	0.50
extractives		1.84	0.85	1.71	0.00	0.86
soluble solids		1.90	0.41	1.25	0.00	0.00
HECs	(%wt)					
cellulose		29.61	34.53	30.15	0.00	31.47
hemi-cellulose		32.26	33.69	31.77	0.00	33.62
lignin		6.34	7.78	6.42	0.00	7.27
ash		3.99	3.63	3.69	0.00	3.77
NS carbohydrates		0.00	0.19	0.00	0.00	0.00
C. protein		7.23	4.41	9.07	0.00	4.96
extractives		7.40	4.42	5.68	0.00	4.97
soluble solids		13.20	11.37	13.23	0.00	13.95

TABLE I-3
AVERAGE CELLULOSIC COMPOSITION BY BIOMASS CLASS AND REGION (BASE ASSUMPTION) (CONTINUED)

		NE	SE/SC	NC	RM	PC
MSW	(%wt)					
cellulose		45.50	45.50	45.50	45.50	45.50
hemi-cellulose		8.50	8.50	8.50	8.50	8.50
lignin		10.00	10.00	10.00	10.00	10.00
ash		15.00	15.00	15.00	15.00	15.00
NS carbohydrates		8.50	8.50	8.50	8.50	8.50
C. protein		3.30	3.30	3.30	3.30	3.30
extractives		6.70	6.70	6.70	6.70	6.70
soluble solids		2.50	2.50	2.50	2.50	2.50
AG RES	(%wt)					
cellulose		33.03	34.67	33.20	33.58	33.03
hemi-cellulose		0.00	2.44	0.00	0.00	0.00
lignin		9.01	10.21	9.07	9.19	9.01
ash		0.00	0.00	0.00	0.00	0.00
NS carbohydrates		0.00	0.00	0.00	0.00	0.00
C. protein		0.00	0.00	0.00	0.00	0.00
extractives		4.00	3.65	4.02	4.06	4.00
soluble solids		53.96	49.02	53.71	53.16	53.95

a. Biomass Class Resource Estimates

SRWCs and HECs

Total biomass resources for SRWCs and HECs, in terms of acreage, were assumed equal to Graham's[6] estimates of 392 million acres. This acreage was limited to all available land on which at least 5 dry tons/acre/year could be produced. Graham's study identified 225 and 324 million acres suitable for growing SRWCs and HEC, respectively, from the 392 million acre resource base. Therefore, 157 million acres met the 5 dry tons/acre/year minimum criteria for both biomass feedstock classes. To avoid double counting these acres, the 157 million acres were divided between the two biomass classes based on their relative potential acreage proportions. As a result, 161 and 231 million acres for SRWCs and HECs respectively were assumed. On a regional basis, each region's acreage contribution to the national total presented by Graham was reduced equally within each biomass class. Table I-4 illustrates the acres, the regional biomass dry ton yields per acre, and resulting regional biomass yield potential for both biomass classes.

As shown in Table I-4, no SRWCs or HECs are expected from the Rocky Mountain Region, as this area is generally believed to be economically inefficient for these two biomass classes. The North Central Region is expected to provide the bulk of these two biomass classes. When the biomass tons are multiplied by the energy contents assumed per dry ton, a total of 17.3 and 26.0 quads are available from SRWC and HEC respectively.

Agricultural Residues

Agricultural residues resource data were primarily derived from Tyson (1991)[7] and Meridian Corporation (1992)[8] reports cited earlier. One of the major assumptions incorporated into BFVM was that current conventional crop types and acreage would be constant through 2030. Table I-5 illustrates the total amount of AR tons available (that are economically feasible to collect) by crop type and region. A total of 0.8 quads are available from ARs. As might be expected, the NC region is assumed to provide the majority of the AR dry tons.

MSW

Population estimates obtained from the U.S. Census Bureaus', Statistical Abstract 1991[9] for the years 1995 and 2000 helped to determine the expected MSW resource base. It was further assumed that 20 percent of the total MSW resource base was unavailable for biomass-to-ethanol conversion due to expected curbside recycling programs (though pre-sorted paper could be a very attractive feedstock option). The Statistical Abstract provides four different series of estimates which vary in assumptions related to immigration, migration, death rate, and birth rate for the various states/regions of the U.S. For simplicity, Series A was chosen.

Population growth projections beyond the year 2000 were based on a 10 year growth rate from 1990 to 2000; this rate was held constant throughout the modeling period.

TABLE I-4
ACREAGE AND YIELD POTENTIAL FOR WOODY AND HERBACEOUS CROPS
(BASED ON AVAILABLE LAND THAT MET A 5 TON/ACRE/YEAR MINIMUM) BY REGION*

	REGION	Acreage (MM acres)	Average Yield (tons/acre/yr)	Region Yield (MM tons/yr)	% of National Yield (%)
	NE	18	5.87	104	10.17%
	SE/SC	50	6.38	322	31.57%
	NC	92	6.36	583	57.26%
	RM	0		0	0.00%
	PC	1	9.00	10	1.01%
Total		161	6.90	1,019	100.00%

	REGION	Acreage (MM acres)	Average Yield (tons/acre/yr)	Region Yield (MM tons/yr)	% of National Yield (%)
	NE	27	6.94	189	10.94%
	SE/SC	83	6.93	577	33.36%
	NC	119	8.03	956	55.25%
	RM	0		0	0.00%
	PC	1	5.62	8	0.44%
Total		231	6.88	1,730	100.00%

* Adjusted to assumed total biomass resource acreage of 392 million acres (Graham 1991)

TABLE I-5
YIELD POTENTIAL FOR AGRICULTURAL RESIDUES BY REGION (MM TONS/YR)

REGION	Corn MM Tons	Sorghum MM Tons	Wheat MM Tons	Sugar Cane MM Tons	Regional Total	% of National Yield (%)
NE	4.49	0.02	1.04	0.00	5.55	9.52%
SE/SC	1.93	0.36	4.95	0.78	8.03	13.77%
NC	29.03	0.84	8.21	0.00	38.09	65.36%
RM	0.35	0.18	2.31	0.00	2.84	4.88%
PC	0.26	0.01	3.49	0.00	3.77	6.47%
Total	36.07	1.42	19.99	0.78	58.27	100.00%

TABLE I-5
YIELD POTENTIAL FOR AGRICULTURAL RESIDUES BY REGION (MM TONS/YR) (CONTINUED)

	REGION	MSW Rate 1995	% of National Yield (%)	MSW Rate 2000	% of National Yield (%)	MSW Rate 2010	% of National Yield (%)
	========	=========	==========	=========	==========	=========	==========
	NE	47	28.94%	48	28.48%	54	27.32%
	SE/SC	50	30.73%	52	31.31%	64	32.71%
	NC	31	19.30%	31	18.66%	35	17.59%
	RM	9	5.63%	10	5.72%	12	5.91%
	PC	25	15.39%	26	15.82%	32	16.48%
Total		162	100.00%	167	100.00%	197	100.00%

	REGION	MSW Rate 2020	% of National Yield (%)	MSW Rate 2030	% of National Yield (%)
	========	=========	==========	=========	==========
	NE	58	26.16%	63	24.99%
	SE/SC	76	34.09%	89	35.47%
	NC	37	16.54%	39	15.52%
	RM	14	6.09%	16	6.26%
	PC	38	17.12%	45	17.75%
Total		223	100.00%	252	100.00%

MSW growth projections beyond the year 2000 were based on a 10 year growth rate from 1990 to 2000. This rate was held constant throughout the modeling period and was applied to the increasing population projections obtained via the methodology described above.

Once these MSW projections were obtained, they were adjusted down by 20 percent to allow for expected MSW recycling programs. By 2030, a total of 202 million tons of raw MSW are expected to be available. However, since this amount includes materials not required for the ethanol conversion process, the cellulosic and organic fractions equalled 140 million tons or 2.3 quads as shown in Table I-5. It should be noted that, while all regions will generate MSW, the majority of this feedstock is expected to come from the SE/SC and NE regions of the U.S.

b. Distribution of National Biomass Production Projections

From 1995 to 2030, the model projects a sizeable shift in the distribution of biomass production among regions which is somewhat expected but worth noting. The NC region dominates total biomass tonnage throughout the modeling period, losing only one percent of the total over the modeled time frame. The greatest difference occurs in the SE/SC region where an increase in its share of total biomass produced from 19% to 32% is realized. This increase coincides with a reduction in the other three regions' (NE, RM, PC) contributions. The largest decline was experienced in the PC region where the contribution fell from 9% to 3%. The diversity and highly suitable land for the production of the feedstocks in the NC and SE/SC regions are the primary factors driving this shift as illustrated in Figure I-2.

It is also interesting to depict this shift in distribution as it relates to feedstock types, as shown in Figure I-3. Based on the assumption that SRWCs and HECs do not come "on-line" until the year 2000, it is expected (and realized) that MSW and AR make-up all biomass production in 1995; specifically, 32% being MSW and 68% ARs. The resulting large contribution from ARs is related to the assumptions affecting availability. As noted above, MSW projections are based on rather conservative assumptions, while AR projections are based on less conservative ones. A more realistic scenario is attained by 2030, where HECs dominate the national biomass tonnage distribution; specifically, HECs account for 65% of the national total biomass tonnage produced. SRWCs and MSW contribute an equal quantity (15%), followed by ARs with 5%. The fact that it is assumed throughout this effort that only one-sixth of the total SRWCs will be harvested annually to maintain a constant feedstock supply, results in the lower, rather unexpected, contribution.

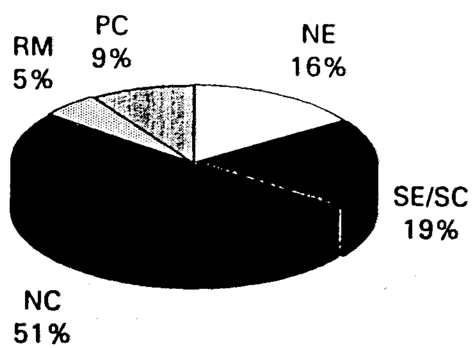
c. Biomass Class Production Assumptions Used in BFVM

Once the four resource bases for the feedstock classes were established, certain assumptions were made regarding the actual timing and volumes for each biomass class. For SRWCs and HECs, the projections provided by Tyson (1990)[10] were used as a guideline. However, some deviations are evident in the BFVM scenarios due, primarily, to harvesting and transportation losses (which will be discussed later). No real guidelines were available for the other two biomass classes.

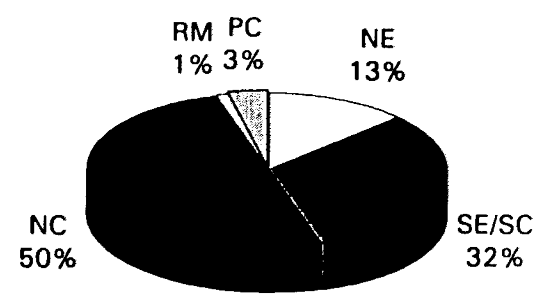
FIGURE I-2
NATIONAL BIOMASS TONNAGE AND PERCENTAGE CONTRIBUTION BY REGION (@ CONVERSION FACILITY)

	1995		2030	
	MM Tons	%	MM Tons	%
NE	6	16%	118	13%
SE/SC	7	19%	297	32%
NC	18	51%	459	50%
RM	2	5%	11	1%
PC	3	9%	32	3%
National Total	35	100%	918	100%

1995 Biomass Distribution by Region



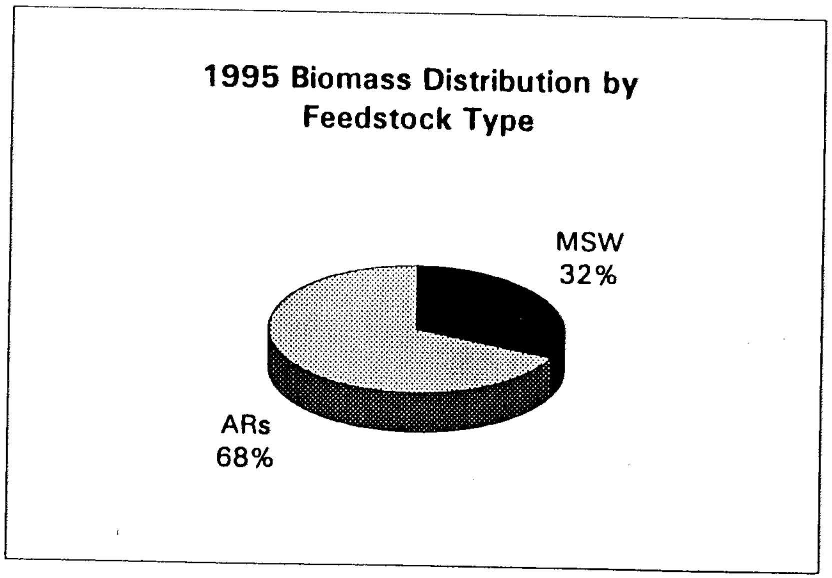
2030 Biomass Distribution by Region

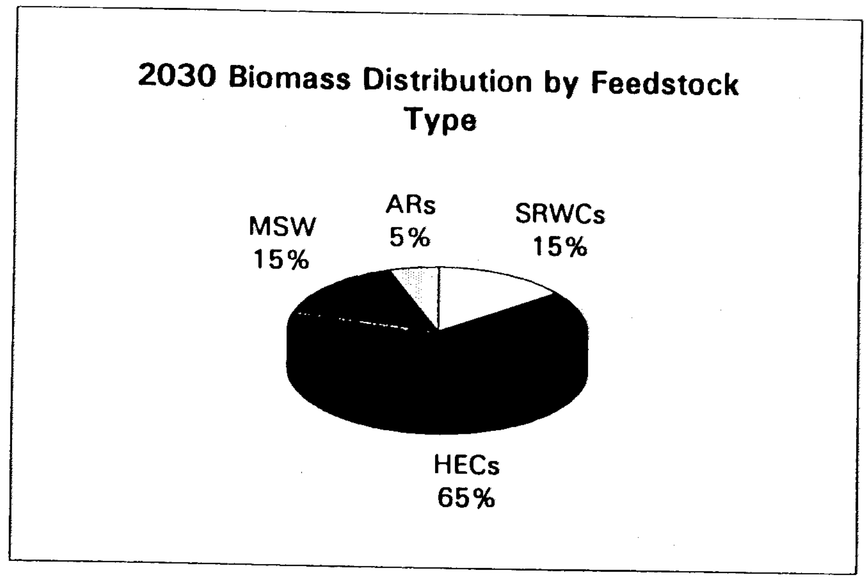


Note : Percentages may not add to 100% due to rounding

FIGURE I-3
NATIONAL BIOMASS TONNAGE AND PERCENTAGE CONTRIBUTION BY FEEDSTOCK TYPE (@ CONVERSION FACILITY)

	1995		2030	
	MM Tons	%	MM Tons	%
SRWCs	0	0%	134	15%
HECs	0	0%	596	65%
MSW	11	32%	140	15%
ARs	24	68%	48	5%
National Total	35	100%	918	100%





d. Biomass Feedstock Availability

ARs and MSW are the two most readily available biomass feedstock classes in the near term. Therefore, as shown in Figure I-4, these feedstocks were assumed to be available by 1995 when the biomass conversion technology is expected to begin to be commercialized. Additionally, since the total amount of tonnage from these two feedstock classes is relatively limited and their prices are cost-effective, it was assumed that 100 percent of the available[1] resource base would be used and maintained through 2030. SRWCs and HECs were assumed not be used until later in the modeled period, due to requirements for establishing annual production and minor technological advancements necessary to achieve cost-effectiveness. Therefore, these two biomass classes are not assumed to be ready until 2000. As Figure I-4 indicates, a much lower percentage of total resource base is assumed. However, the biomass resource bases for each of these classes are much larger than those for ARs or MSW, leading to much larger quantities of biomass feedstock being derived from SRWCs and HECs.

Figure I-5 illustrates the outcome of the production assumptions presented above in terms of quadrillion BTUs (quads). The amounts of biomass feedstock presented are before sorting, harvesting, and transportation losses are taken into account. These losses are discussed in the next section.

6. Harvesting and Transportation Losses

Most of the harvesting and transportation losses assumptions were derived from the TFCA. As mentioned earlier, it was assumed that the five site-specific data points used in the TFCA would be representative of the regions in the BFVM. Implicit in this assumption, are the distances travelled in storing and transporting the different feedstocks. In addition, the TFCA did not provide information for all of the biomass classes analyzed by the BFVM. Therefore, approximate loss data were used for other regions, where possible, for the same biomass class (i.e., herbaceous crops in the Pacific Coast Regions utilized data from herbaceous crops transported similar distances in the Northeast). For simplicity in this effort, a composite average of 18% losses, based on TFCA and other sources, was applied to SRWC, HEC, and ARs in the model. MSW losses were directly from the TFCA and are made up of sorting/preparation losses (29%) and transportation losses (1%). Table I-6 provides the assumed losses for each region, biomass class within a region, and the aggregate loss total for all of the biomass classes combined within a region.

[1]For ARs, net of residues for ground cover, harvesting, and transportation losses. For MSW, net of recycling, sorting/preparation losses and transportation losses.

FIGURE I-4
PERCENTAGE OF BIOMASS CLASS RESOURCE BASE ASSUMED AVAILABLE FOR ETOH CONVERSION

	1995	2000	2010	2020	2030
SRWCs	0%	6%	10%	13%	16%
HECs	0%	4%	13%	23%	42%
ARs	50%	100%	100%	100%	100%
MSW	10%	40%	80%	80%	80%

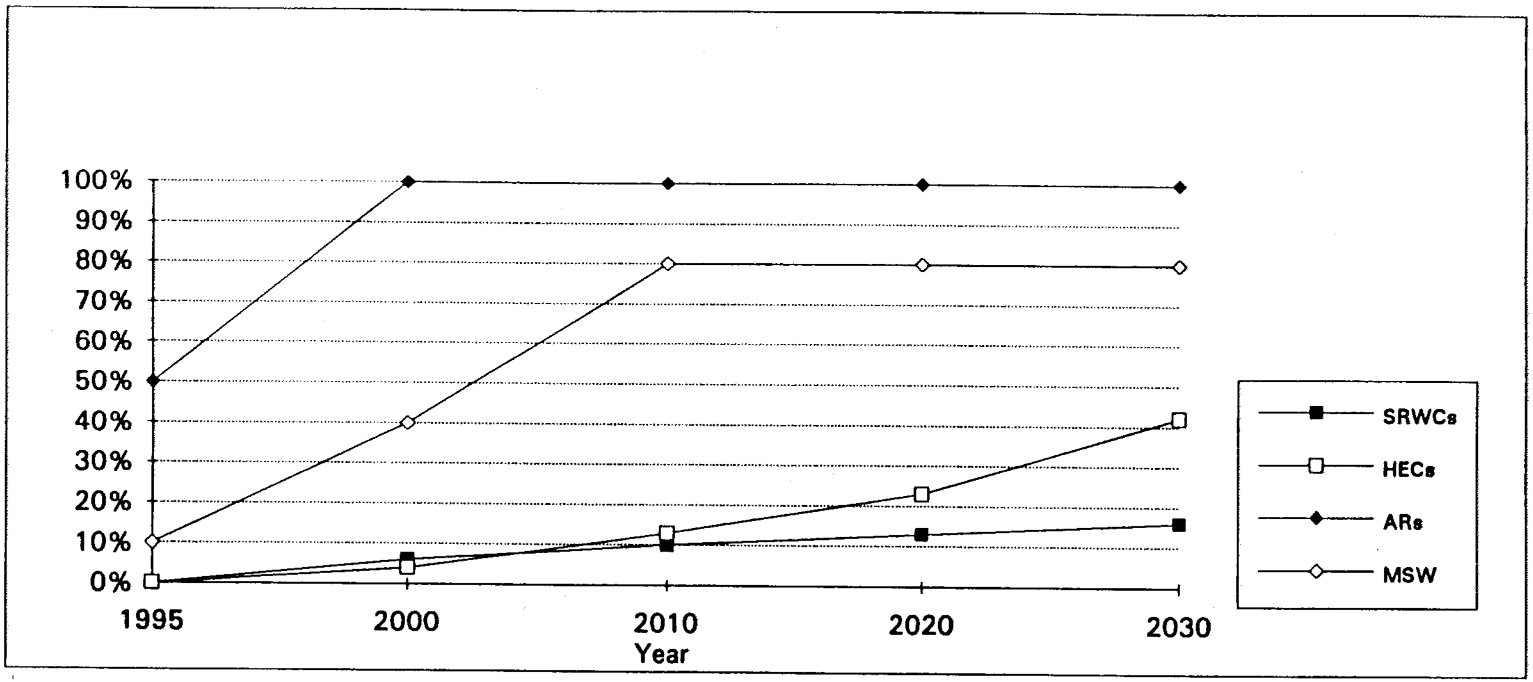


FIGURE I-5
BIOMASS PRODUCTION (QUADS) AT PRODUCTION/HARVESTING & CURB-SIDE SITE (PRE-LOSS)

	1995	2000	2010	2020	2030
ARs	0.41	0.82	0.82	0.82	0.82
MSW	0.26	1.07	2.52	2.85	3.23
SRWCs	0.00	1.04	1.73	2.25	2.77
HECs	0.00	1.04	3.37	5.97	10.90

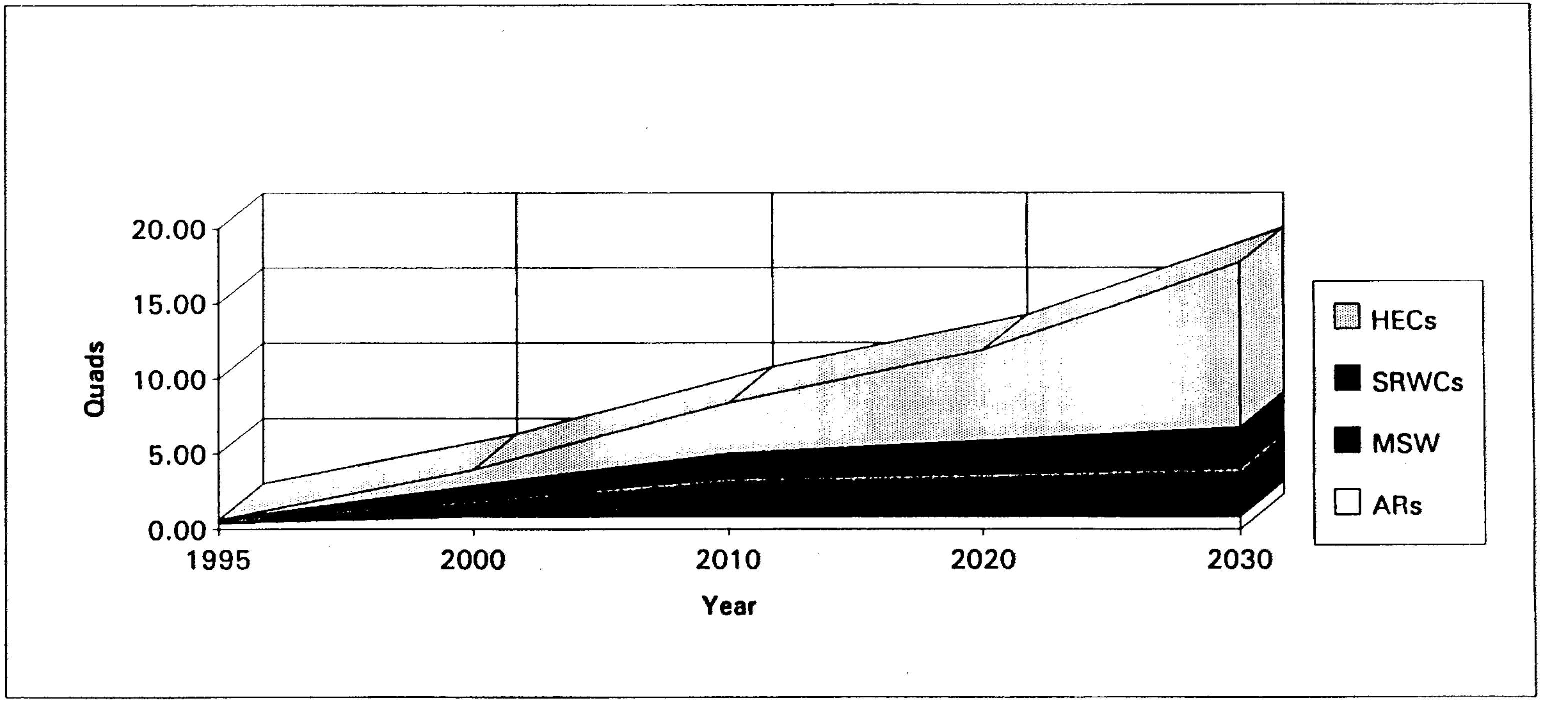


TABLE I-6
FEEDSTOCK LOSSES

Region/Feedstock	Resource Base Potential tons	Losses Transportation/Harvesting tons	%	Sorting/Prep tons	%	Potential Total at EtOH Facility tons
Northeast						
Trees	16,570,171	2,982,631	18%	N/A	N/A	13,587,541
Grasses	79,532,400	14,315,832	18%	N/A	N/A	65,216,568
E. Cane/Sorghum	0	0	18%	N/A	N/A	0
Ag Residues	5,547,900	998,622	18%	N/A	N/A	4,549,278
MSW	50,446,556	528,236	1%	14,614,534	29%	35,303,785
Southeast/Southcentral						
Trees	51,456,686	9,262,203	18%	N/A	N/A	42,194,482
Grasses	197,615,903	35,570,862	18%	N/A	N/A	162,045,040
E. Cane/Sorghum	44,857,598	8,074,368	18%	N/A	N/A	36,783,230
Ag Residues	8,026,000	1,444,680	18%	N/A	N/A	6,581,320
MSW	71,585,818	749,590	1%	20,738,649	29%	50,097,580
Northcentral						
Trees	93,328,457	16,799,122	18%	N/A	N/A	76,529,335
Grasses	305,201,028	54,936,185	18%	N/A	N/A	250,264,843
E. Cane/Sorghum	96,379,272	17,348,269	18%	N/A	N/A	79,031,003
Ag Residues	38,085,500	6,855,390	18%	N/A	N/A	31,230,110
MSW	31,327,989	328,042	1%	9,075,822	29%	21,924,125

TABLE I-6
FEEDSTOCK LOSSES (CONTINUED)

Region/Feedstock	Resource Base Potential tons	Losses Transportation/Harvesting tons	%	Sorting/Prep tons	%	Potential Total at EtOH Facility tons
Rocky Mountain						
Trees	0	0	18%	N/A	N/A	0
Grasses	0	0	18%	N/A	N/A	0
E. Cane/Sorghum	0	0	18%	N/A	N/A	0
Ag Residues	2,842,100	511,578	18%	N/A	N/A	2,330,522
MSW	12,641,686	132,374	1%	3,662,338	29%	8,846,974
Pacific						
Trees	1,645,714	296,229	18%	N/A	N/A	1,349,486
Grasses	3,203,400	576,612	18%	N/A	N/A	2,626,788
E. Cane/Sorghum	0	0	18%	N/A	N/A	0
Ag Residues	3,772,000	678,960	18%	N/A	N/A	3,093,040
MSW	35,828,150	375,164	1%	10,379,534	29%	25,073,452

7. Feedstock Related Emissions

a. Harvesting and Transportation Overview

Emissions data for 1995 and 2030 are presented in Tables I-7 and I-8 for both production/harvesting or sorting/preparation and transportation, based on the harvesting and transportation scenarios mentioned earlier. Factors listed as "nil" coincide with emissions that were not significant and were referred to as "nd", indicating that no data were available for that category. These emission factors, located in Appendix A, for harvesting and transportation were derived from TFCA summary sheets. It should be noted that some inconsistencies do exist for the emissions data. For example, the emissions data for the MSW was for the 2000 time frame while the harvesting and production of SRWCs and HECs was assumed to be in the 2010 time frame. Likewise, the harvesting emissions data for herbicides and pesticides is assumed to be 40% lower than current emissions. No adjustments to account for these minor variations have been conducted. The emissions data presented in the TFCA were assumed in the BFVM to be constant over the years analyzed.

b. Harvesting

Emissions data are calculated by feedstock type and region based on tonnage and resulting million british thermal units (MMBtu's). These MMBtu's are then multiplied by an emission factor which is feedstock and regionally specific.

c. Transportation

In the case of transportation emissions, it was assumed that all biomass tonnage would be transported by diesel truck. Although this may not be the most efficient mode of transportation for some regions, it does provide for consistency across all regions. Emissions data were based on the number of tons transported to the ethanol conversion facility. For ease of the modeling effort, the distances travelled for each type of feedstock were derived from TFCA.

d. MSW Transportation and Sorting Emissions

As shown in Tables I-9 and I-10, MSW sorting/preparation and transportation emissions are quite different from the other three biomass classes. The MSW related emissions are due to the transportation of the MSW from a transfer station to the sorting/preparation facility. Emissions occurring at earlier stages, due to garbage truck MSW collection, are not included in the model since it is assumed these emissions would occur regardless of the existence of an ethanol conversion facility. Once the MSW is delivered to the sorting/preparation facility, emissions result from the size reduction and sorting of the raw MSW. The BFVM currently considers all of the emissions released during processing of the raw MSW. This assumption may need to be adjusted in later modeling efforts to only the cellulosic and organic fraction of the MSW used by the ethanol conversion facility. Once the cellulosic and organic fractions have been separated, only these portions of the MSW are transported to the ethanol conversion facility.

TABLE I-7
FEEDSTOCK PRODUCTION/HARVESTING EMISSIONS

	1995			
	SRWCs	HECs		ARs
		Perennial	Annual	
National Total Tonnage (MM Tons)	0	0	0	29
Quads	0.00	0.00	0.00	0.41
Production/Harvesting Emissions				
Outputs/Releases				
Air Releases (100 Tons/Yr)				
HC	0	0	0	10
CO	0	0	0	42
NOx	0	0	0	42
PM	0	0	0	4
VOCs	0.00	0.00	0.00	0.00
Aldehydes	0.00	0.00	0.00	0.00
CO2 - fossil fuel	0	0	0	5,608
SO2	0.00	0.00	0.00	1.76
N-fertilizer	0	0	0	174
P2O5 - fertilizer	0.00	0.00	0.00	0.00
K2O - fertilizer	0.00	0.00	0.00	0.00
Herbicides	0.00	0.00	0.00	1.80
Insecticides	0.00	0.00	0.00	0.41
Soil (wind erosion)	0	0	0	8,691
Isoprene	0.00	0.00	0.00	0.00
Monoterpene	0.00	0.00	0.00	0.00

TABLE I-7
FEEDSTOCK PRODUCTION/HARVESTING EMISSIONS (CONTINUED)

	1995			
	SRWCs	HECs		ARs
		Perennial	Annual	
Water Releases (100 Tons/Yr)				
Surface Water				
N - fertilizer	0	0	0	87
P2O5 - fertilizer	0	0	0	56
K2O - fertilizer	0	0	0	83
Herbicides	0.00	0.00	0.00	0.23
Insecticides	0.00	0.00	0.00	0.05
Soil (dissolved soln)	0	0	0	5,015
Ground Water				
N - fertilizer	0	0	0	87
P2O5 - fertilizer	0	0	0	56
K2O - fertilizer	0	0	0	83
Herbicides	0.00	0.00	0.00	0.19
Insecticides	0.00	0.00	0.00	0.05
Land Erosion (100 Tons/Yr)				
N - fertilizer	0	0	0	87
P2O5 - fertilizer	0	0	0	111
K2O - fertilizer	0	0	0	83
Herbicides	0.00	0.00	0.00	0.12
Insecticides	0.00	0.00	0.00	0.02
Soil (Runoff)	0	0	0	36,448

TABLE I-7
FEEDSTOCK PRODUCTION/HARVESTING EMISSIONS (CONTINUED)

TABLE I-7
FEEDSTOCK PRODUCTION/HARVESTING EMISSIONS (Cont'd)

Table I - 7

Feedstock Production/Harvesting Emissions

	2030			
	SRWCs	HECs		ARs
		Perennial	Annual	
National Total Tonnage (MM Tons)	163	588	139	58
Quads	2.77	8.81	2.09	0.82
Production/Harvesting Emissions				
Outputs/Releases				
Air Releases (100 Tons/Yr)				
HC	59	209	35	19
CO	258	912	150	84
NOx	258	912	150	84
PM	27	97	16	9
VOCs	0	0	0	0
Aldehydes	0	0	0	0
CO2 - fossil fuel	34,195	121,140	19,930	11,217
SO2	10.76	38	6.28	3.52
N-fertilizer	466	3,614	1,001	348
P2O5 - fertilizer	0.00	0.00	0.00	0.00
K2O - fertilizer	0.00	0.00	0.00	0.00
Herbicides	17.08	39.55	46.16	3.59
Insecticides	1.42	8.94	11.54	0.83
Soil (wind erosion)	45,921	156,579	100,981	17,382
Isoprene	29,035	0	0	0
Monoterpene	328	0	64	0

TABLE I-7
FEEDSTOCK PRODUCTION/HARVESTING EMISSIONS (CONTINUED)

		2030		
	SRWCs	HECs		ARs
		Perennial	Annual	
Water Releases (100 Tons/Yr)				
Surface Water				
N - fertilizer	232	1,807	618	174
P2O5 - fertilizer	69	1,198	180	111
K2O - fertilizer	69	1,797	1,718	167
Herbicides	2.28	5.16	6.14	0.47
Insecticides	0.14	1.15	1.55	0.10
Soil (dissolved soln)	25,115	93,049	51,577	10,031
Ground Water				
N - fertilizer	232	1,807	855	174
P2O5 - fertilizer	69	1,198	180	111
K2O - fertilizer	69	1,797	247	167
Herbicides	1.37	4.07	4.94	0.37
Insecticides	0.14	0.94	1.20	0.09
Land Erosion (100 Tons/Yr)				
N - fertilizer	232	1,807	618	174
P2O5 - fertilizer	138	2,397	359	223
K2O - fertilizer	69	1,797	247	167
Herbicides	6.89	2.62	3.07	0.23
Insecticides	0.00	0.50	0.74	0.05
Soil (Runoff)	180,118	680,871	363,208	72,897

TABLE I-8
SRWC, HEC, AND AR TRANSPORTATION EMISSIONS

	1995			
	SRWCs	HECs		ARs
		Perennial	Annual	
National Total Tonnage (MM Tons)	0	0	0	24
Quads	0.00	0.00	0.00	0.33
Transportation Emissions				
Outputs/Releases				
Air Releases (100 Tons/Yr)				
HC	0.00	0.00	0.00	1.39
CO	0	0	0	6
NOx	0	0	0	6
PM	0.00	0.00	0.00	0.22
VOCs				
Aldehydes				
CO2 - fuel	0	0	0	1,765
SO2	0.00	0.00	0.00	0.55
CO2 - decompostion	0	0	0	69,342

TABLE I-8
SRWC, HEC, AND AR TRANSPORTATION EMISSIONS (CONTINUED)

	2030			
	SRWCs	HECs		ARs
		Perennial	Annual	
National Total Tonnage (MM Tons)	134	482	114	48
Quads	2.27	7.23	1.71	0.67
Transportation Emissions				
Outputs/Releases				
<u>Air Releases</u> (100 Tons/Yr)				
HC	10.02	32.48	7.38	2.78
CO	40	130	29	11
NOx	40	130	29	11
PM	1.61	5.22	1.19	0.45
VOCs				
Aldehydes				
CO2 - fuel	12,704	41,202	9,353	3,530
SO2	3.97	12.88	2.92	1.11
CO2 - decompostion	485,005	1,534,733	379,729	138,684

TABLE I-9
MSW SORTING/PREPARATION EMISSIONS

		1995 MSW	2030 MSW
National Total Tonnage (MM Tons)		16	200
Quads		0.26	3.20
Sort/Prep Emission			
Outputs/Releases			
Air Releases	(100 Tons/Yr)		
Diesel Emissions			
HC		0.46	5.75
CO		1.74	21.74
NOx		3.58	44.60
PM		0.30	3.79
VOCs		0.00	0.00
Aldehydes		0.00	0.00
CO2		32	396
SO2		0.12	1.52
Air Releases (Cont'd)	(100 Tons/Yr)		
Process Emissions			
Dust		1.26	15.71
Cd		0.00	0.04
Pb		0.01	0.08
Hg		0.00	0.01
Cr		0.01	0.08
Ni		0.01	0.11
Water Releases (to sewer systems) In MM Gallons		1,784	22,251
Land Concerns	(100 Tons/Yr)		
Solid Wastes		0.00	0.00

TABLE I-10
MSW TRANSPORTATION EMISSIONS

		1995 MSW	2030 MSW
National Total Tonnage (MM Tons)		16	202
Quads		0.26	3.23
Transportation #1 Emissions			
Outputs/Releases			
Air Releases	(100 Tons/Yr)		
Diesel Emissions			
	HC	1.51	18.89
	CO	4.56	56.84
	NOx	5.77	72.01
	PM	0.12	1.52
	VOCs	0.00	0.00
	Aldehydes	0.00	0.00
	CO2	83	1,032
	SO2	0.31	3.92
Tonnage (MM Tons)		11	142
Quads		0.18	2.27
Transportation #2 Emissions			
Outputs/Releases			
Air Releases	(100 Tons/Yr)		
Diesel Emissions			
	HC	2.08	25.99
	CO	6.24	77.86
	NOx	7.91	98.63
	PM	0.17	2.08
	VOCs	0.00	0.00
	Aldehydes	0.00	0.00
	CO2	1,138	14,187
	SO2	0.43	5.37

As such, MSW transportation related emissions were attributed to only these fractions of the MSW.

e. SRWCs and HECs Emissions

When analyzing the emissions related to specific feedstocks for specific regions (in Appendix A), it is apparent that some regions do not exhibit emissions tonnage for specified feedstocks and, as such, only zeros are shown in the tables. This is the case since none of the crops shown below were modeled for those regions.

Region	Feedstock
NE	Annual crops (E. Cane/Sorghum)
RM	Woody crops
	Perennial grasses
	Annual crops (E. Cane/Sorghum)
PC	Annual crops (E. Cane/Sorghum)

Likewise, the emissions related to the transportation of these feedstocks, in their respective regions, are non-existent. They are merely presented here to demonstrate the flexibility of the model to accommodate scenarios which might incorporate the growing of these crops in any region. Additionally, in 1995 for both SRWCs and HECs, no emissions are projected due to the assumption that these feedstocks are not available until the year 2000.

8. Feedstock Costs

Data for feedstock costs were derived from several sources. The cost information has been adjusted to 1990 constant dollars to allow for direct cost comparisons without having to assume future inflation rates.

a. SRWCs and HECs

Feedstock production costs for SRWCs and HECs were derived from Tyson's (1990)[11] study. To simplify the cost calculations, a straight arithmetic average of land groups II and III was used since these land groups are considered to have the greatest likelihood of utilization for energy crops. Land groups II and III are defined, verbatim, as in Tyson's report[12] and are provided below :

> Land Group II - soils have severe limitations that reduce the choice of plants or require moderate conservation practices. The soils can be used for cultivated crops, pasture, range, forest, or wildlife habitat. If cultivated, they need careful management, including conservation practices, to prevent their deterioration or to improve air and water relationships. The limitations are few, however, and the practices are easy to apply.

Land Group III - soils have severe limitations. The limitations reduce the choice of plants or require special conservation practices, or both. The soils can be used for cultivated crops, pasture, forest, range, or wildlife habitat. If these soils are cultivated, very careful management is needed, and conservation practices are very difficult to apply.

In cases where projected crops grown in various regions did not coincide with either Tyson or TFCA, a national average (based on Tyson's numbers) was assumed for the respective regions (e.g., costs realized for HECs in the North Central region were assumed representative of costs for grasses in the Northeast). Table I-11 shows the results of these calculation on per dry ton basis for both SRWCs and HECs.

Since projected crop specialization differs among regions and studies, various production costs were assumed representative of entire crop classifications. Consequently, switchgrass production costs were representative of all perennial grasses, hybrid poplar was assumed indicative of all woody (tree) crops, and energy sorghum was assumed demonstrative of all annual crops.

b. Agricultural Residues

Delivered costs for agricultural residues are assumed to be constant across all regions. The costs associated with sugar cane are assumed to be equal to corn and sorghum (which is roughly the average of the majority of agricultural residues' costs based on WAPAP report)[13]. Additionally, due to a lack of information, it was assumed that the costs of these ARs, as shown in Table I-12, would be constant over time.

c. MSW

MSW delivered costs were assumed to equal $10.75 per dry ton and remain constant through 2030. This cost was assumed to be a conservative estimate since most municipal sanitation agencies are currently paying "tipping fees" to dispose of their MSW. This MSW tipping fee can range from $10 to $90 per ton. In addition, due to a limited amount of landfill space, it is generally believed that these tipping fees will increase as transportation distances increase and landfill space decreases. However, the cost of sorting the raw MSW, and uncertainties regarding the possibility of earning income from the unnecessary MSW sorted fractions (i.e., aluminum) from recycling, the $10.75 was felt to be realistic until more detailed analyses could be performed.

TABLE I-11
NATIONAL AVERAGE COSTS BY CROP
($/DRY TON)

	1990 Land Groups *			1995 Land Groups *		
	II	III	AVG	II	III	AVG
<u>Switchgrass</u>						
NE						
SE/SC	87.04	106.84	96.94	73.71	90.08	81.89
NC	86.74	103.85	95.30	75.55	90.17	82.86
RM						
PC						
Nat Average			96.12			82.37
<u>Hybrid Poplar</u>						
NE	75.72	94.54	85.13	70.42	87.71	79.06
SE/SC						
NC	69.83	86.70	78.27	64.49	79.84	72.16
RM						
PC	53.09	65.41	59.25	49.39	60.65	55.02
Nat Average			74.22			68.75
<u>E. Sorghum</u>						
NE						
SE/SC						
NC	50.94	55.93	53.44	45.03	49.30	47.17
RM						
PC						
Nat Average			53.44			47.17

* See text citing figure for explanation of land group definitions

TABLE I-11
NATIONAL AVERAGE COSTS BY CROP
($/DRY TON) (CONTINUED)

	2000 Land Groups *			2010 Land Groups *		
	II	III	AVG	II	III	AVG
Switchgrass						
NE						
SE/SC	60.37	73.32	66.85	47.96	57.72	52.84
NC	64.35	76.48	70.42	56.27	66.88	61.58
RM						
PC						
Nat Average			68.63			57.21
Hybrid Poplar						
NE	65.11	80.87	72.99	55.42	68.37	61.90
SE/SC						
NC	59.14	72.98	66.06	49.60	60.69	55.15
RM						
PC	45.69	55.89	50.79	37.82	45.73	41.78
Nat Average			63.28			52.94
E. Sorghum						
NE						
SE/SC						
NC	39.12	42.67	40.90	32.78	35.56	34.17
RM						
PC						
Nat Average			40.90			34.17

* See text citing figure for explanation of land group definitions

TABLE I-11
NATIONAL AVERAGE COSTS BY CROP
($/DRY TON) (CONTINUED)

	2020 Land Groups *			2030 Land Groups *		
	II	III	AVG	II	III	AVG
Switchgrass						
NE						
SE/SC	45.88	55.10	50.49	44.02	52.76	48.39
NC	53.46	63.43	58.45	51.57	61.11	56.34
RM						
PC						
Nat Average			54.47			52.37
Hybrid Poplar						
NE	52.51	64.63	58.57	50.00	61.43	55.72
SE/SC						
NC	45.08	54.93	50.01	44.48	54.18	49.33
RM						
PC	36.38	43.89	40.14	35.22	42.41	38.82
Nat Average			49.67			47.95
E. Sorghum						
NE						
SE/SC						
NC	31.56	34.19	32.88	30.47	32.97	31.72
RM						
PC						
Nat Average			32.88			31.72

* See text citing figure for explanation of land group definitions

TABLE I-12
DELIVERED COSTS OF ARS AND MSW
(1990 $/DRY TON)

	$/Dry Ton					
	1990	1995	2000	2010	2020	2030
AR						
Corn	40.00	40.00	40.00	40.00	40.00	40.00
Sorghum	40.00	40.00	40.00	40.00	40.00	40.00
Wheat	34.88	34.88	34.88	34.88	34.88	34.88
Sugar Cane	40.00	40.00	40.00	40.00	40.00	40.00
MSW	10.75	10.75	10.75	10.75	10.75	10.75

d. Total Production Costs

Figures I-6 and I-7 graphically depict the production costs for all biomass tonnage, by feedstock, for 1995 and 2030, respectively. It should be noted that the cost scale (in $millions) changes from figure I-6 to I-7. This was done to accommodate the 50-fold increase in biomass production (from SRWCs and HECs coming on line) from 1995 to 2030. Clearly, in both figures, the NC region accounts for over half the total production costs for the entire nation; specifically 60% in 1995, and 52% in 2030.

These results coincide with the biomass production projections presented earlier that show the North Central region with the potential for growing the most diversified feedstock blends and the largest quantities associated with these feedstocks. Over the same time period, the SE/SC region increases its contribution from 16% to 32% (1995 to 2030). Again, this is what would be expected since this region is second only to the NC in level of feedstock diversification and quantity produced. Both of these regions produce large quantities of the more expensive feedstocks and are less reliant on MSW and ARs. The other three regions-- NE, RM, and PC -- decline from approximately 25% to 15% aggregate contribution over the modeling period. The smaller quantities of feedstock (primarily SRWCs and MSW) produced translate into much lower production costs relative to the other two regions.

FIGURE I-6
TOTAL FEEDSTOCK COST BY REGION
1995

	Million $	%
NE	159	12%
SE/SC	201	16%
NC	774	60%
RM	61	5%
PC	93	7%
National Total	1,288	100%

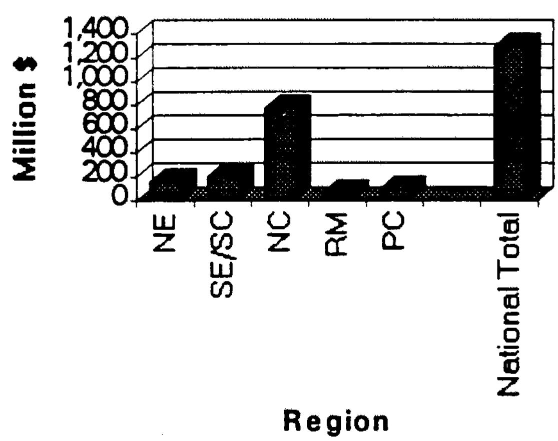
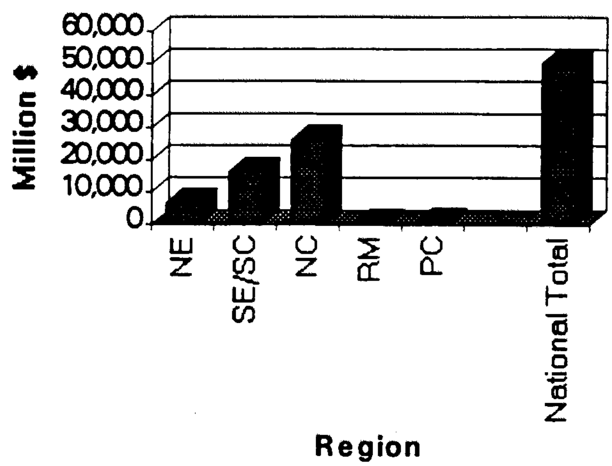


FIGURE I-7
TOTAL FEEDSTOCK COSTS BY REGION
2030

	Million $	%
NE	6,613	13%
SE/SC	16,270	32%
NC	26,309	52%
RM	238	0%
PC	817	2%
National Total	50,246	100%



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II. CHARACTERIZATION OF BIOMASS-TO-ETHANOL CONVERSION

1. Biomass-to-Ethanol Variability Model (BTEVM)

In order to fully characterize the process of converting biomass to ethanol, a flexible computer model entitled the "Biomass-to-Ethanol Variability Model (BTEVM)" has been developed for this effort. Given a feedstock of specified composition, and knowing the capacity and design parameters of an ethanol facility, the BTEVM will:

- compute the expected amount of ethanol product;
- estimate the required amounts of chemicals and other raw materials necessary for the production of ethanol;
- determine the required utilities;
- estimate the amounts of air, water and land emissions from, both, the processing and boiler operations; and
- estimate the factory-gate (or wholesale) price of the resulting ethanol product.

The BTEVM is used to compare the use of four biomass feedstocks: short rotation woody crops (SRWC), herbaceous energy crops (HEC), municipal solid wastes (MSW), and agricultural residues (AR). In addition, this model is divided into three modules: the Biomass-to-Ethanol Performance Model (BTEPM), the Biomass-to-Ethanol Emissions Model (BTEEM), and the Biomass-to-Ethanol Economic Model (BTEEcM). A brief description of each module is presented below.

2. Biomass-to-Ethanol Performance Model (BTEPM)

The BTEPM has been developed to characterize an ethanol conversion facility utilizing the Simultaneous Saccharification and Fermentation (SSF) process being developed at the National Renewable Energy Laboratory (NREL). Information and data on the SSF process is based on reports, papers, and studies published by NREL.

The model compares the performance of the SSF conversion process for the four different classes of feedstocks mentioned above. As such, the BTEPM has four components that correspond to SRWC, HEC, MSW, and AR feedstocks. Since only scattered data on the feedstocks were available, several assumptions have been made to develop this model. Data on woody and herbaceous crops were extracted from NREL's Total Fuel Cycle Analysis (1991).[14] The SRWC conversion component is based on an annual feedstock blend representative of the Pacific Coast region. The HEC conversion component is based on an annual feedstock blend representative of the North Central region. The agricultural residues conversion component is representative of the Southeast/South Central region and the MSW portion is a nationwide average. The composition of these four classes of feedstocks is shown in Table II-1. SRWC and HEC feedstocks have the highest content of fermentable sugars, while agricultural residues are characterized by a lower content of fermentable sugars and a very high content of soluble solids. MSW is also very high in fermentable sugars and non-soluble carbohydrates.

TABLE II-1
FEEDSTOCK COMPOSITION AS REALIZED BY BTEVM

Feedstock Composition % wt	SRWC	HEC	MSW	AR
Cellulose	48.78	30.15	45.50	34.67
Hemicellulose	18.78	31.77	8.50	2.44
Lignin	26.24	6.42	10.00	10.21
Ash	1.63	3.69	15.00	0.00
N.S. Carbohydrates	3.20	0.00	8.50	0.00
Crude Protein	0.50	9.07	3.30	0.00
Extractives	0.86	5.68	6.70	3.65
Soluble Solids	0.00	13.23	2.50	49.02

a. Time Frame

The model is used to characterize the conversion process from 1995 through the year 2030.

b. Process Steps

Major process steps include feedstock handling and size reduction, prehydrolysis/neutralization, xylose conversion, cellulose production, SSF process, ethanol recovery, waste treatment and utilities.

c. Process Parameters

The model captures the results of varying several parameters within given intervals. These include:

Hemicellulose to xylose:	80 - 90%
Hemicellulose unconverted:	7 - 0%
Hemicellulose to furfural:	13 - 10%
Xylose to ethanol:	90 - 95%
Cellulase yield:	202 IU - 470 IU
Cellulose to ethanol:	72 - 90%
Cellulose to protein cells:	10 - 5%
Cellulose unconverted:	13 - 0%
Ethanol Recovery:	95.0 - 99.9%
Steam Req. (lb/gal ethanol):	25.8 - 16.5 lbs./gal ethanol
Chipping Power (kWhr/ton):	
Woody Crops:	5.5 - 2.5 kWhr/ton
Herbaceous Crops:	2.1 - 1.0 kWhr/ton
MSW:	3.3 - 1.5 kWhr/ton
Agricultural Residues:	3.3 - 1.5 kWhr/ton
Milling Power (hp hr/dry ton):	
Woody Crops:	128 - 100 hp hr/dry ton
Herbaceous Crops:	80 - 40 hp hr/dry ton
MSW:	100 - 50 hp hr/dry ton
Agricultural Residues:	100 - 50 hp hr/dry ton
Soluble solids to biogas:	90 - 95%
Xylose to biogas:	90 - 95%
Furfural to biogas:	90 - 95%
Glycerol to biogas:	90 - 95%

d. Chemical Input Requirements

The most important chemical input required for the conversion facility is the biomass feedstock itself. For the first year (1995), the conversion plant design is based on a feedstock rate of 160,000 lb/hr or 640,000 tons per year (the equivalent of 2000 tons/day), for an on-stream time of 8,000 hours per year. The feedstock rate increases over years and reaches 223,100 lb/hr or 892,397 tons per year in 2030.

In addition to the feedstock, large amounts of several other chemicals are required for the conversion process steps to run smoothly. Some of these chemicals directly participate in the main reaction. This is the case for sulfuric acid, which is needed for the prehydrolysis, and the lime used in the neutralization step following prehydrolysis. In this step, the lime reacts with the sulfuric acid to neutralize the material from the prehydrolysis reactor, prior to fermentation. Other chemicals, such as nutrients, corn steep liquor (CSL), ammonia, etc., are used as a source of nutrients for microorganisms.

Several chemicals are required to treat boiler feedwater before the water can be fed to the high pressure boiler. Chemicals used to treat cooling water include inhibitors to prevent scale formation on heat exchanger surfaces and a biocide to prevent buildup of algae and other types of microorganisms in the circulating cooling water. Several types of nutrients are also used as chemicals for the microorganisms in the waste water treatment system.

Low-sulfur diesel fuel is used by equipment such as front end loaders and tractors, which are used in the feedstock handling area to move the feedstock from the storage piles to conveyors. Gasoline is required in the product storage area to denature the ethanol product.

A detailed listing of major chemical inputs and their required amounts is shown in Tables II-2 and II-3 for the years 1995 and 2030, respectively.

e. Utilities

The model compares the required utilities for different feedstocks from 1995 through 2030. The utilities included account for the efficiency of the boiler/turbo-generator; the electricity produced, consumed and sold to the grid; the steam requirement; the plant requirement for cooling water, chilled water, and process air. The summary of ethanol conversion process utilities as projected by the model for 1995 and 2030 is given in Table II-4, while Figure II-1 shows a summary of ethanol conversion process electricity utilization for 1995 and 2030. The process produces more electricity than needed to run the plant, resulting in a surplus that could be sold to the grid.

f. Outputs

Table II-5 presents a summary of the outputs of the conversion process as projected by the model for 1995 and 2030, assuming a 2,000 ton/day facility. Model projections for ethanol production based on the classes and amounts of feedstock available from 1995 through 2030 are provided in the Section II.5. In addition to ethanol product, gasoline, acetaldehyde and electricity, the process output includes several tons of solid waste and sludge. The BTEVM projects the different amounts of potential outputs based on the same amounts of each feedstock over the modeled time frames.

Figure II-2 shows ethanol throughput projections from BTEVM (1995-2030) as a function of each class of biomass feedstocks. Of the four feedstocks considered here, SRWC seems to provide higher ethanol throughputs, followed by herbaceous crops. Agricultural residues seem to provide the least ethanol throughput, which is the result of this feedstock's poor composition.

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TABLE II-2
BIOMASS CONVERSION INPUTS SUMMARY AS PROJECTED BY BTEVM (1995)

Input Summary for Conversion Process		SRWC (1995)	HEC (1995)	MSW (1995)	ARs (1995)
Chemical Inputs	tons/yr				
Feedstock (dry)		0	0	640,000	640,000
Sulfuric Acid		0	0	11,099	11,099
Lime		0	0	8,181	8,181
Ammonia		0	0	8,763	26,826
CS Liquor		0	0	1,226	692
Nutrients		0	0	354	200
Antifoam		0	0	77	42
Glucose		0	0	1,414	1,316
Boiler Chemicals					
Na2PO4		0	0	0	1
Amine		0	0	1	2
Hydrazine		0	0	4	5
Cooling Water Chemicals					
Silicate		0	0	3	3
Phosphonate		0	0	1	1
Polyphosphate		0	0	4	4
Orthophosphate		0	0	4	4
Zinc		0	0	2	2
Waste Water Chemicals					
Urea		0	0	591	1,190
Triple Super Phosphate		0	0	242	0
Polymer		0	0	5	465
Water (MM gal/yr)		0	0	653	588
Limestone		0	0	1,647	1,334
Fuels Input (1000 gal/yr)					
National Gasoline Total		0	0	42,290	62,979
Diesel		0	0	98	196
Labor Input (employees)					
Supervisors		0	0	9	9
Operators		0	0	37	37
Maintenance		0	0	36	36

TABLE II-3
BIOMASS CONVERSION INPUTS SUMMARY AS PROJECTED BY BTEVM (2030)

Input Summary for Conversion Process		2030 SRWC	2030 HEC	2030 MSW	2030 ARs
Chemical Inputs	tons/yr				
Feedstock (dry)		892,397	892,397	892,397	892,397
Sulfuric Acid		15,352	15,352	15,477	15,477
Lime		11,308	11,333	11,408	11,408
Ammonia		24,613	38,055	12,219	37,406
CS Liquor		1,323	836	1,710	965
Nutrients		381	241	493	278
Antifoam		80	54	107	59
Glucose		2,334	1,648	1,972	1,835
Boiler Chemicals					
Na2PO4		1	1	1	1
Amine		3	2	2	2
Hydrazine		10	6	6	7
Cooling Water Chemicals					
Silicate		6	4	5	4
Phosphonate		2	2	2	2
Polyphosphate		8	5	6	6
Orthophosphate		8	5	6	6
Zinc		4	3	3	3
Waste Water Chemicals					
Urea		986	1,872	824	1,660
Triple Super Phosphate		374	736	337	0
Polymer		0	0	7	649
Water (MM gal/yr)		1,145	793	911	820
Limestone		1,036	2,858	2,297	1,860
Fuels Input (1000 gal/yr)					
National Gasoline Total		662,942	2,655,970	562,380	132,514
Diesel		243	136	136	273
Labor Input (employees)					
Supervisors		12	12	12	12
Operators		51	51	51	51
Maintenance		50	50	50	50

TABLE II-4
BIOMASS CONVERSION PROCESS UTILITIES SUMMARY AS PROJECTED BY BTEVM

Utilities :		1995			
		SRWC	HEC	MSW	ARs
Efficiency of Boiler/Turbo Generator	%	77%	74%	69%	76%
Plant Electricity Produced	KW	0.0	0.0	18.3	23.5
Plant Electricity Consumed	KW	0.0	0.0	10.8	11.1
Plant Electricity Sold	KW	0.0	0.0	7.5	12.4
Plant Steam Requirement :					
50 psig	lb/hr	0	0	143,217	152,168
150 psig	lb/hr	0	0	38,579	70,445
Plant Cooling Water Requirement	GPM	0	0	40,280	36,789
Plant Chilled Water Requirement					
3.6 F delta T	GPM	0	0	816	495
27 F delta T	GPM	0	0	616	374
Plant Process Air Requirement	lb/hr	0	0	21,214	15,217

Utilities :		2030			
		SRWC	HEC	MSW	ARs
Efficiency of Boiler/Turbo Generator	%	77%	74%	69%	76%
Plant Electricity Produced	KW	52.5	30.1	25.6	32.8
Plant Electricity Consumed	KW	20.5	13.0	15.1	15.5
Plant Electricity Sold	KW	32.1	17.1	10.5	17.3
Plant Steam Requirement :					
50 psig	lb/hr	265,847	199,697	199,697	212,178
150 psig	lb/hr	84,622	89,115	53,793	98,226
Plant Cooling Water Requirement	GPM	74,138	47,428	56,165	51,297
Plant Chilled Water Requirement					
3.6 F delta T	GPM	939	610	1,138	690
27 F delta T	GPM	709	461	859	521
Plant Process Air Requirement	lb/hr	27,458	18,971	29,580	21,218

FIGURE II-1
CONVERSION PROCESS ELECTRICITY UTILIZATION

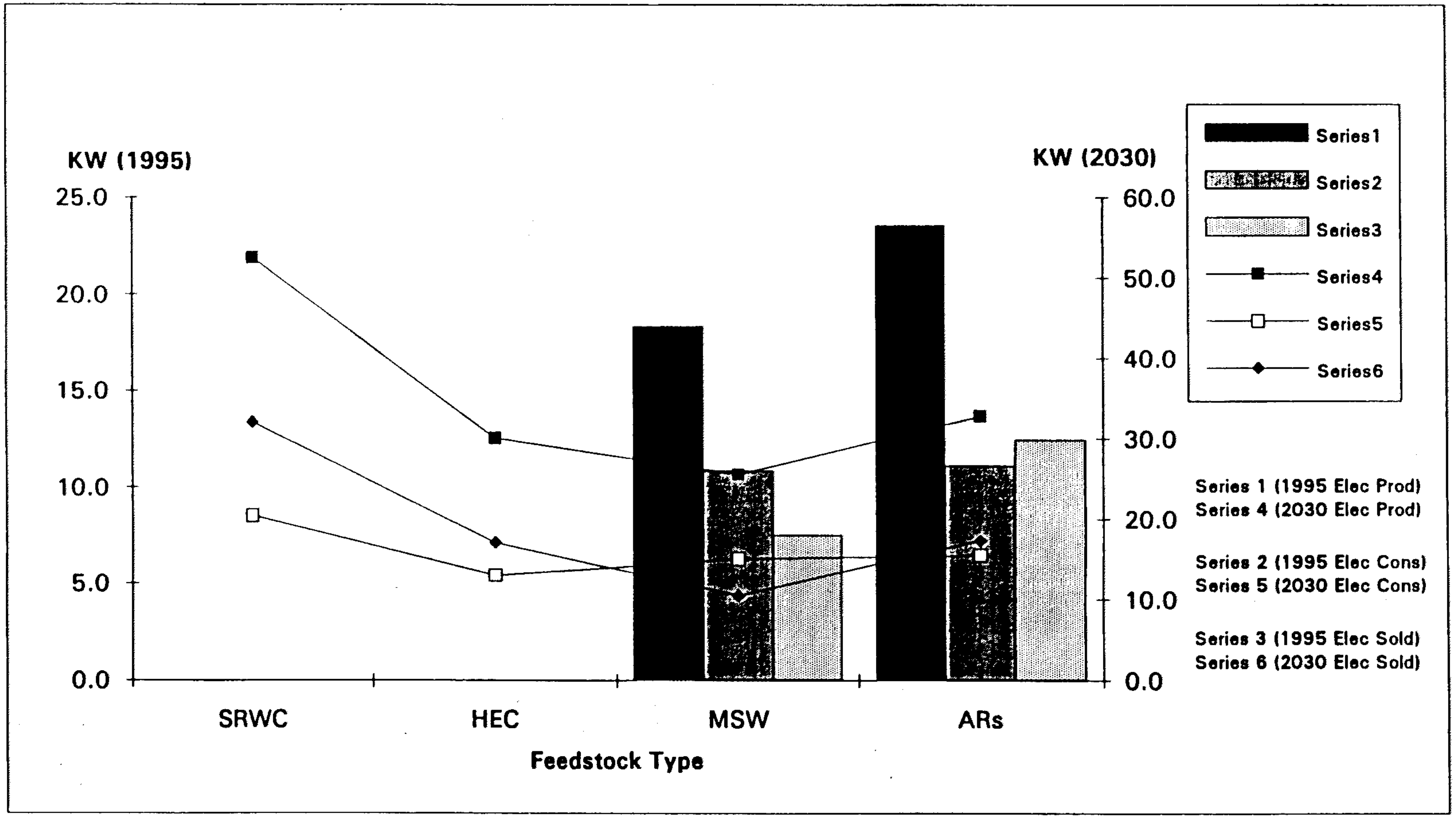


TABLE II-5
BIOMASS CONVERSION PROCESS OUTPUT SUMMARY

Output Summary for Conversion Process	1995 SRWC	1995 HEC	1995 MSW	1995 ARs
Denatured Fuel :				
National Ethanol Total (MM gal/yr)	0.00	0.00	845.81	1259.58
National Gasoline Total (1000 gal/yr)	0	0	42,290	62,979
Acetaldehyde (ton/yr)	0	0	89	73
Solid Waste (ton/yr)	0	0	116,811	38,848
Sludge (ton/yr)	0	0	0	2,256
Electricity (kWh x10^6/yr)	0	0	64	107

Output Summary for Conversion Process	2030 SRWC	2030 HEC	2030 MSW	2030 ARs
Denatured Fuel :				
National Ethanol Total (MM gal/yr)	13258.84	53119.40	11247.61	2650.27
National Gasoline Total (1000 gal/yr)	662,942	2,655,970	562,380	132,514
Acetaldehyde (ton/yr)	112	91	124	102
Solid Waste (ton/yr)	45,182	82,625	162,878	54,168
Sludge (ton/yr)	4,643	2,459	0	3,145
Electricity (kWh x10^6/yr)	275	147	90	149

FIGURE II-2
ETHANOL THROUGHPUT PROJECTIONS AS A FUNCTION OF FEEDSTOCK COMPOSITION (MILLION GALLONS/YEAR)

	1995	2000	2010	2020	2030
SRWCs	0.00	59.06	67.58	77.56	88.52
HECs	0.00	51.08	59.20	68.99	79.54
MSW	48.06	48.57	55.24	62.93	71.47
ARs	33.74	34.10	38.61	43.74	49.50

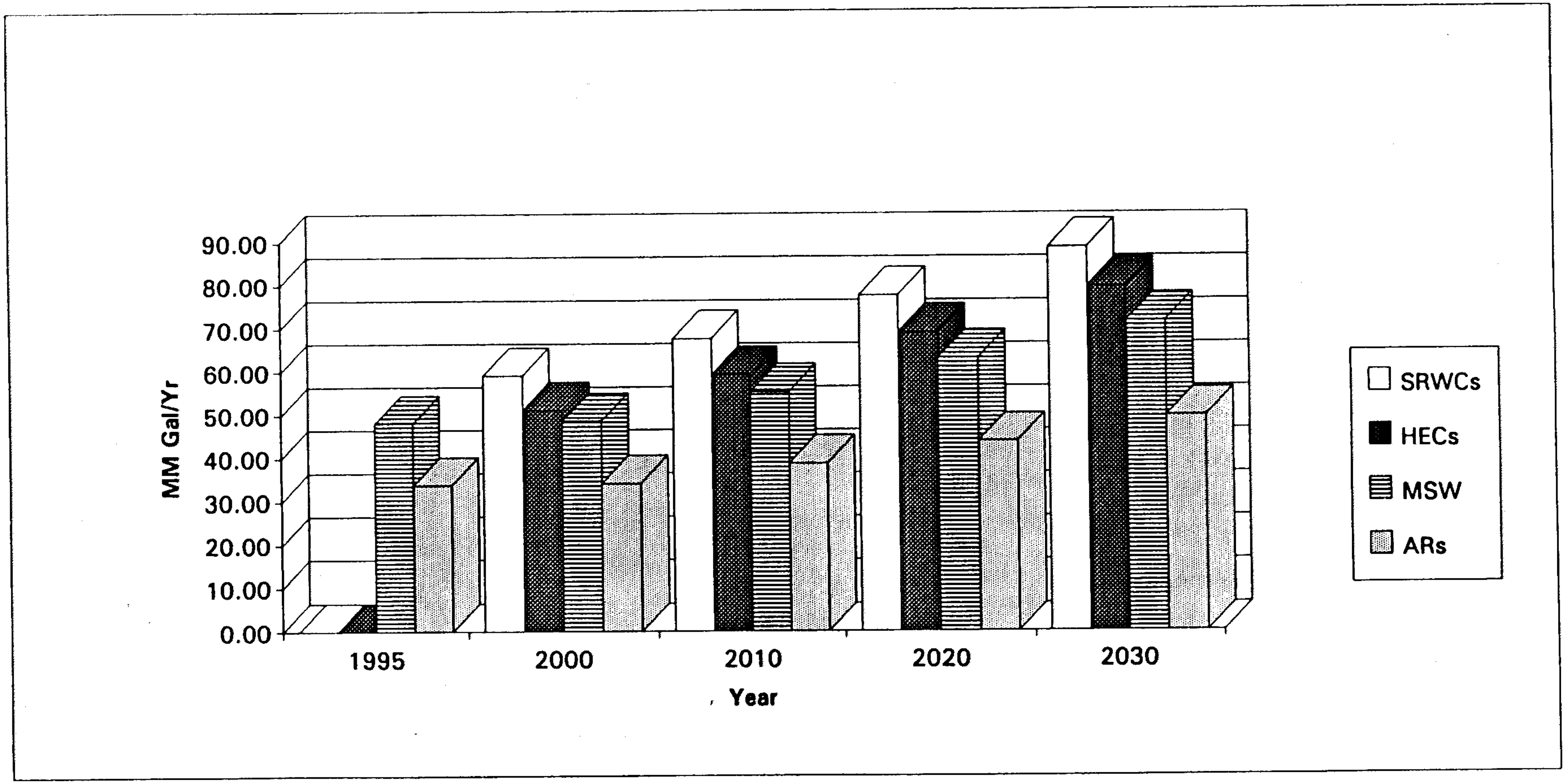


Figure II-3 shows daily biomass feedstock requirements to produce 58 million gallons of ethanol per year in 2000. To produce a given amount of ethanol, the feedstock showing the lowest daily requirement is SRWC, while the highest is agricultural residues.

Figure II-4 shows the effect of technology progress on the biomass-to-ethanol conversion factor, defined as the number of gallons of ethanol per ton of biomass feedstock. This biomass-to-ethanol conversion factor increases steadily from 1995 through 2030 as the result of improved process efficiencies and technological breakthroughs.

3. Biomass-to-Ethanol Emissions Model (BTEEM)

During the conversion process, each conversion step becomes an environmental concern. As part of the BTEVM a spreadsheet module, the Biomass-to-Ethanol Emissions Model (BTEEM), was developed to compare air releases, water releases, land releases, and boiler emissions during the conversion of SRWC, HEC, MSW, and AR from 1995 through 2030. Tables II-6 and II-7 show the tonnage of various emissions released to the air, water, and the land by the processing of different biomass feedstocks, and by the boiler of an ethanol facility (of 160,000 lb/hr of biomass feedstock or 2,000 tons/day), as projected by BTEEM for 1995 and 2030, respectively. Carbon dioxide, suspended solids and biological oxygen demand by waste waters are the major environmental concerns.

4. Biomass-to-Ethanol Economic Model (BTEEcM)

This module of the BTEVM, the Biomass-to-Ethanol Economic Model (BTEEcM), was developed to gauge the cost of ethanol from woody crops, herbaceous crops, MSW and agricultural residues from 1995 through 2030. Because of the scarcity of available data, several assumptions have been made.

a. Capital Cost

The model assumes the use of the same conversion equipment for all feedstocks. This results in the same capital cost for woody crops, herbaceous crops, MSW, and agricultural residues.

b. Capital Investment Return Rate

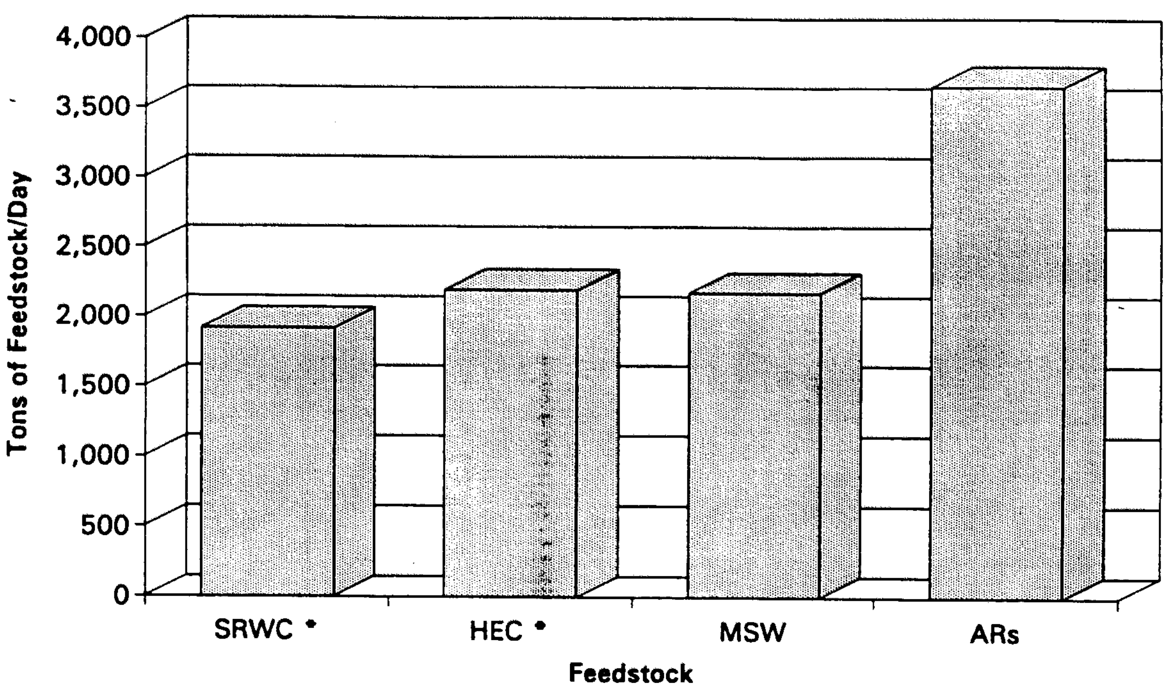
An annual capital charge of 20% is assumed.

c. Cost of Production

For the first year (1995), the model is based on a feedstock rate of 160,000 lb/hr (2,000 tons/day) or 640,000 tons per year for an on-stream time of 8,000 hours per year.

FIGURE II-3
DAILY BIOMASS FEEDSTOCK REQUIREMENTS TO PRODUCE 58 MILLION GALLONS OF ETOH PER YEAR

	SRWC *	HEC *	MSW	ARs
gal/ton	90.71	79.37	80.11	47.58
Throughput	58,053,853	58,053,853	58,053,853	58,053,853
biomass tons/yr	640,000	731,407	724,644	1,220,191
biomass tons/day	1,920	2,194	2,174	3,661



* These conversion factors represent status of the technology and production potential in 1995, if these feedstocks are available then.

FIGURE II-4
VARIATION OF BIOMASS-TO-ETOH CONVERSION FOR ALL FEEDSTOCKS DUE TO IMPROVED EFFICIENCIES AND TECHNOLOGICAL BREAKTHROUGHS

	SRWCs	HECs	MSW	ARs
1995	0.00	0.00	75.10	52.72
2000	92.28	79.82	75.89	53.27
2010	94.52	82.80	77.25	53.99
2020	97.09	86.37	78.78	54.76
2030	99.20	89.13	80.08	55.46

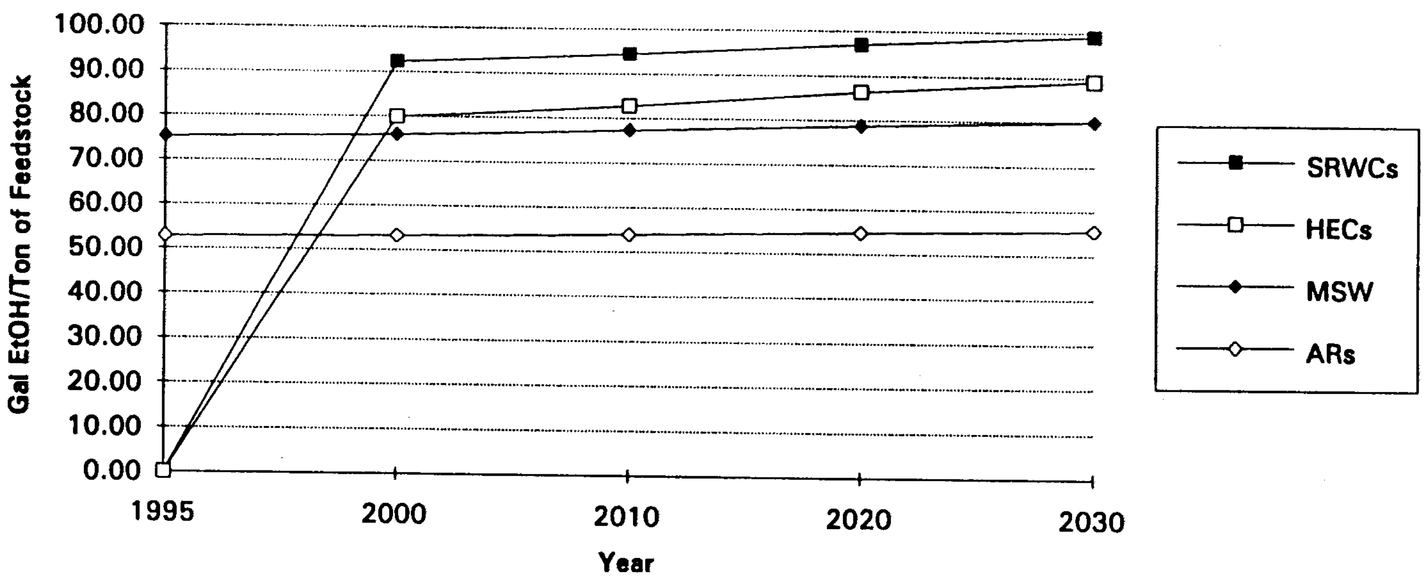


TABLE II-6
EMISSIONS FROM BTEVM BY TYPE
OF RELEASE FOR ALL FEEDSTOCKS (1995)

	1995			
AIR RELEASES tons/year	SRWC	HEC	MSW	ARs
CO2	0	0	835,808	635,725
CO	0	0	322	280
SO2	0.0	0.0	80.1	45.5
NOx	0.0	0.0	178.1	157.0
PM-10	0.0	0.0	417.6	91.3
Pb	0.00	0.00	0.03	0.00
HCl	0	0	64	0
VOC - Total	0.0	0.0	54.0	46.9
Gasoline	0.00	0.00	0.96	0.67
Diesel	0.00000	0.00000	0.00215	0.00198
Ethanol	0.0	0.0	6.1	4.7
Acetaldehyde	0.000	0.000	0.818	0.615
Formaldehyde	0.000	0.000	0.533	0.410
Ammonia	0.0	0.0	33.9	27.1
WATER RELEASES tons/year				
Suspended Solids	0	0	553	370
Oil & Grease	0	0	0	0
COD	0	0	664	444
Thermal	0	0	0	0
LAND CONCERNS				
Land Area (acres)	0	0	50	50

TABLE II-7
EMISSIONS FROM BTEVM BY TYPE OF RELEASE FOR ALL FEEDSTOCKS (2030)

	2030			
AIR RELEASES tons/year	SRWC	HEC	MSW	ARs
CO2	1,919,745	1,463,687	1,242,807	932,573
CO	988	596	480	411
SO2	356.4	165.4	119.0	66.8
NOx	538.3	371.6	264.8	230.3
PM-10	290.5	202.2	621.0	134.0
Pb	0.00	0.00	0.04	0.00
HCl	0	0	95	0
VOC - Total	165.5	101.9	80.4	68.7
Gasoline	1.77	1.59	1.43	0.99
Diesel	0.00493	0.00356	0.00320	0.00290
Ethanol	13.4	11.7	9.1	6.9
Acetaldehyde	2.152	1.451	1.217	0.903
Formaldehyde	1.399	0.967	0.792	0.602
Ammonia	89.4	59.9	50.4	39.8
WATER RELEASES tons/year				
Suspended Solids	1231	771	823	543
Oil & Grease	0	0	0	0
COD	1476	925	987	652
Thermal	0	0	0	0
LAND CONCERNS				
Land Area (acres)	50	50	50	50

The cost of production can be divided into several categories, including:

Raw Materials:

These raw materials were discussed in the technical performance model. The most important raw material of interest here is the feedstock.

The production costs for SRWC and HEC are from a recent report by S. K. Tyson (1990).[15] The production cost for MSW was derived from data reported by the TVA (1991)[16] and EPA (1992).[17] Other cost figures are from ChemSystems' Study (1990).[18] The production cost for agricultural residues is from Tyson and Sairek (1991).[19] The figure of $39.44/ton, was used, which is the average cost of production of several types of agricultural residues, including wheat, corn, sorghum, sunflower, barley, oat, rye, flax, rice, and cotton.

The analysis shows that the cost of feedstock contributes up to 60% of total cash cost (except the annual capital charge). In the first years of operation, the tipping fee has a significant impact on MSW feedstock cost, which becomes negative and therefore, results in the lowest ethanol product price. But, by the year 2030 the tipping fee becomes high enough to result in a non-negative MSW cost. These findings are confirmed by Figure II-5, which shows the projections of ethanol costs from BTEEcM(1995-2030) for the four classes biomass feedstocks.

Utilities:

Utilities are primarily electricity and water. Detailed utilities are provided in BTEPM (see Appendix B).

Operating Costs:

These include labor for operating the plant as well as materials and labor for annual maintenance.

Overhead Expenses:

These include plant overhead, taxes and insurance. A detailed cost estimate is presented in the Economic Model BTEEcM (Appendix B) for all four feedstocks from 1995 through 2030.

5. Model Projections (1995-2030)

In Section I of this report, certain assumptions were made as to the year and volume the potential resource base for each biomass class would be available to biomass ethanol conversion facilities. Of the four biomass feedstock classes analyzed by this effort, MSW and Ar are the only two currently and readily available biomass feedstock classes. Therefore, these two resources are assumed to be available by 1995, while SRWCs and HECs, which require more time for their establishment are assumed not to be available until 2000. Even from 2000-2030, increasingly-greater portions of the potential resource base are assumed to be available.

The amount of nationwide biomass feedstock tonnage available for ethanol conversion has been projected for 1995 through 2030. As shown in Figure II-6, HECs will provide the greatest tonnage, increasing from 0 tons per year in 1995 to 600 million tons per year in 2030. The second largest contributor to total biomass tonnage is MSW, varying from 11.3 million tons in 1995 to 140.4 million tons in 2030. SWRCs follow with 0 tons in 1995 and 134 million tons in 2030. The least amount of biomass tonnage comes from ARs, account for approximately 24 million tons in 1995 and 48 million tons in 2030.

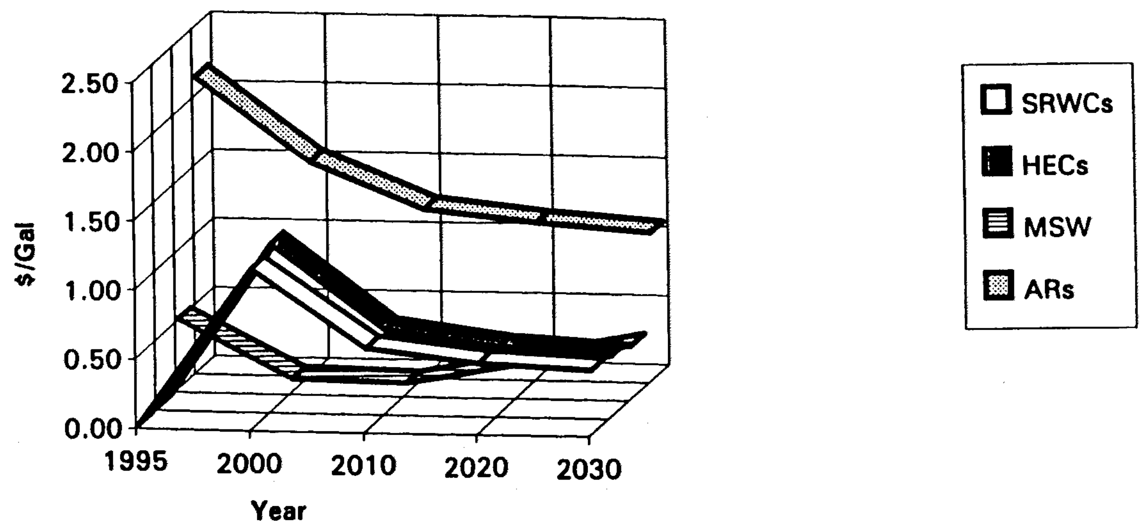
Although the per-plant biomass conversion/ethanol production projections (based on feedstock composition) from BTEVM (1995-2030) show that SRWCs have the highest conversion efficiencies (99.20 gallons/ton versus 89.13 for HEC, 80.08 for MSW, and 55.46 for AR in 2030), the nationwide ethanol throughput projections for BTEVM (1995-2030) in Figure II-7 show that HECs have the highest ethanol production potential, varying from 0 gallon per year in 1995 to 53.1 billion gallons per year in 2030. This is due to the greater resource base for HECs available for ethanol conversion.

Figure II-7 also shows that, combined, all four biomass feedstock classes have the potential to produce a nationwide amount of ethanol increasing from 2.1 billion gallons per year in 1995 to 80.3 billion gallons in 2030. As emphasized in Figure II-8, these nationwide ethanol projections represent 0.16 quads per year in 1995 and 6.1 quads by 2030.

Based on a typical plant designed to process 2000 tons of feedstock per day (the smallest such plant considered economical), 1,029 such plants would be required by 2030 to achieve the levels of ethanol mentioned above (80.3 billion gallons). While it is expected that some larger conversion facilities will be built, it was beyond the scope of this effort to speculate on the subject. The number of 2000 ton/day plants mentioned above produces a base-line for future analysis. The distribution of these plants based on different biomass feedstock classes (1995-2030) shows that the ethanol production potential for SRWCs slows down because of the six-year rotation during feedstock production. Also, despite increases in population, the growth of MSW feedstock is affected by increased recycling efforts. HECs are the only feedstock class that shows a steadily growing ethanol production potential.

FIGURE II-5
PROJECTIONS OF ETOH COSTS FROM BTEVM (1995-2030)

	1995	2000	2010	2020	2030
SRWCs	0.00	1.15	0.59	0.49	0.46
HECs	0.00	1.20	0.59	0.48	0.43
MSW	0.51	0.09	0.08	0.22	0.38
ARs	2.13	1.53	1.20	1.12	1.06



Variation of Biomass-to-EtOH Conversion

FIGURE II-6
BIOMASS AVAILABLE TO CONVERSION FACILITIES BY YEAR AND FEEDSTOCK CLASS
(MM TONS/YEAR)

Feedstock Tonnage (MM Tons)

	SRWCs	HECs	MSW	ARs
1995	0	0	11	24
2000	50	57	46	48
2010	84	184	110	48
2020	109	326	124	48
2030	134	596	140	48

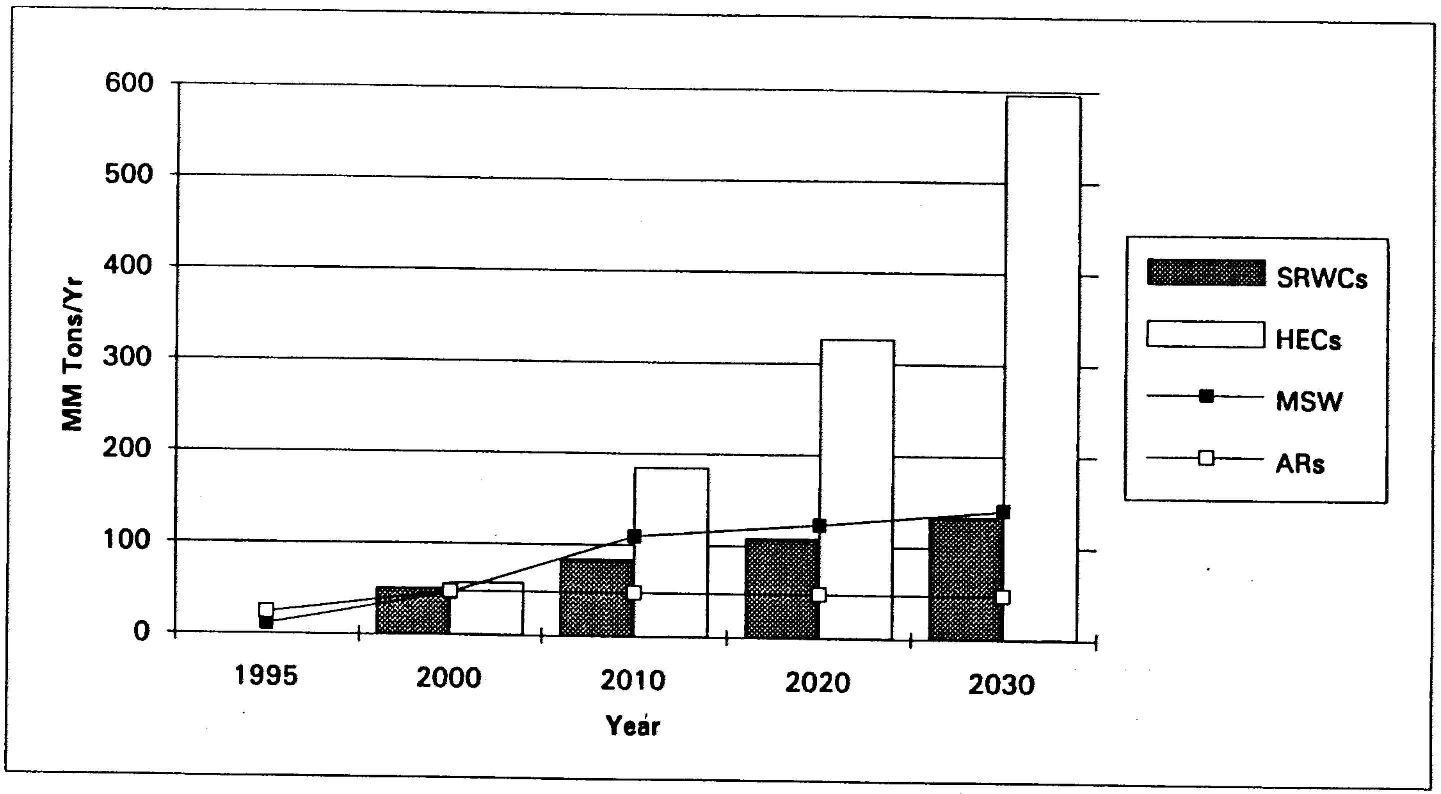


FIGURE II-7
ETHANOL THROUGHPUT PROJECTIONS BY YEAR AND FEEDSTOCK CLASS
(MM GAL/YR)

	1995	2000	2010	2020	2030
SRWCs	0	4,625	7,896	10,544	13,259
HECs	0	4,530	15,274	28,186	53,119
MSW	846	3,525	8,473	9,767	11,248
ARs	1,260	2,546	2,580	2,617	2,650
Total	2,105	15,226	34,223	51,114	80,276

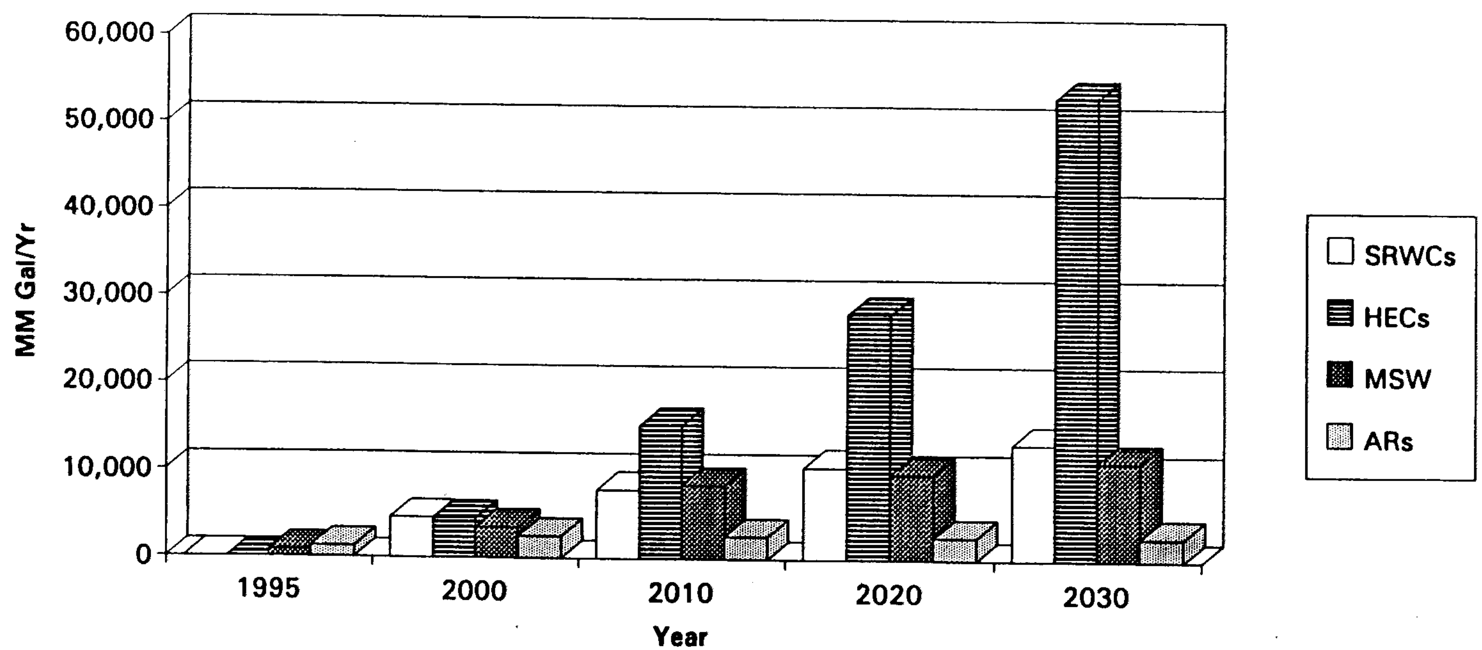
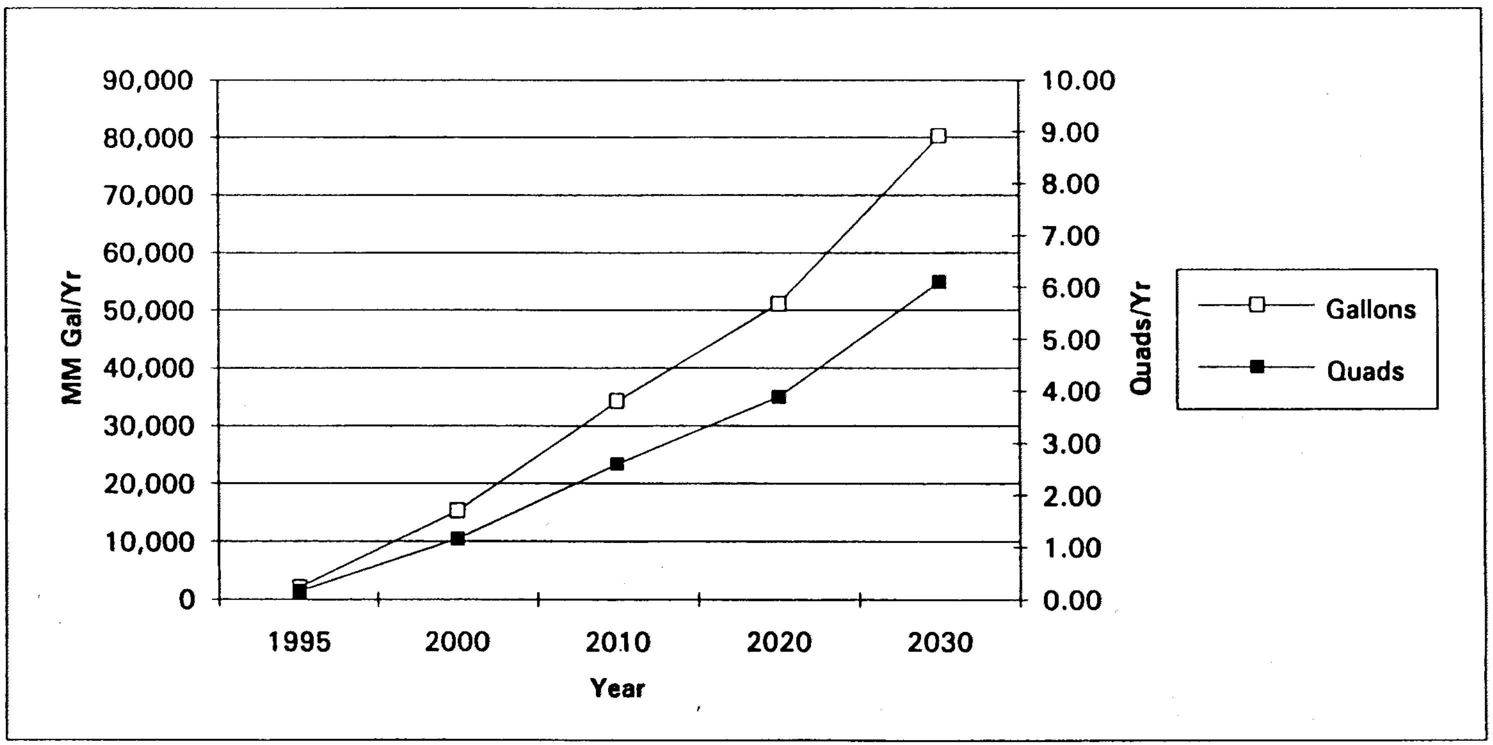


FIGURE II-8
TOTAL ETHANOL PRODUCTION
(IN GALLONS AND QUADS)

	SRWCs	HECs	MSW	ARs	Total Gallons	Total Quads
1995	0	0	846	1,260	2,105	0.16
2000	4,625	4,530	3,525	2,546	15,226	1.16
2010	7,896	15,274	8,473	2,580	34,223	2.60
2020	10,544	28,186	9,767	2,617	51,114	3.88
2030	13,259	53,119	11,248	2,650	80,276	6.10



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III. CHARACTERIZATION OF ETHANOL USE

1. Ethanol Transportation and Distribution

In the near- to mid-term, through 2010, it is generally assumed that all ethanol batches, including both blends and neat, will be transported by tank trucks and rail cars. Existing tanks, used to transport conventional fuels, are largely sufficient for this purpose. It is also assumed that the distribution of ethanol will involve transporting the product directly from the production site to bulk plants for blending. These sites will serve as the wholesale distribution centers for commercial accounts and service stations.

After 2010, the expected higher levels of ethanol production, supported by the commercialization of ethanol flexible-fuel vehicles (FFV) and a dedicated vehicle fleet, will make it more economical to incorporate product pipelines into the ethanol distribution network. It is likely that product pipelines will carry a portion of the ethanol from production facilities to bulk product terminals and/or bulk plants for blending or storage. Distribution to commercial accounts or service stations will largely occur through tank trucks, as is the case currently with conventional gasoline.

While the existing liquid fuels distribution infrastructure is largely adequate to facilitate the transportation and storage of ethanol and ethanol blended fuels. Lower level blends of ethanol, including E10, present a problem in the form of phase separation, which occurs when water intrudes the transportation medium. The alcohol in E10 can separate from the gasoline when as little as 0.2% water comes into contact with the fuel. At higher level blends, such as E85 and E95 used for dedicated vehicles, there is no phase separation problem. Improved distribution maintenance, the use of chemical additives, and other phase separation inhibitors can limit the problem for low level ethanol blends. However, these methods can be expensive and may affect the overall cost of transporting and distributing ethanol blended fuels.

Once ethanol supply and demand reach higher levels (2010), it is expected that the use of pipelines will be incorporated into the distribution network. In the long run, pipelines should offer a more efficient means of transporting the fuel. Yet this occurrence is dependent on the development of a dedicated ethanol pipeline network, or improved techniques for limiting the challenge of phase separation with lower level blends.

a. Cost Indicators

The current cost estimate for the transportation and distribution of gasoline from the production facility to the retail outlet is approximately $0.01 per gallon.[20] This cost is not expected to change through 2030 beyond the rate of inflation.

The cost of transporting and distributing E95 is estimated to be approximately 25% more than conventional gasoline since pipelines and tanks would require additional cleaning following an

E95 shipment. Thus the cost per gallon to transport and distribute E95 is estimated to be $0.0125.

E10, however, will likely be more expensive to handle given the potential for phase separation. Several methods, including chemical additives, have the potential to effectively resolve the phase separation problem.[21] This will likely add 50% to the cost of shipping conventional gasoline, resulting in a per gallon cost of $0.015.

The levelized cost of energy (LCOE) distributed through the existing liquid fuels infrastructure will be higher than the per Btu cost associated with distributing conventional gasoline, since the energy content of ethanol is lower. Therefore, in order to supply the same quantity of energy through ethanol fuels, a larger volume of fuel must be supplied. E95 contains 67% of the energy density of conventional gasoline, so the per Btu cost of distributing E95 is estimated at $0.0166 (1.33 x $0.0125). E10 contains 97% of the energy density of conventional gasoline, thus the per Btu cost of distributing E10 is estimated at $0.01545 (1.03 x $0.015).

b. Effluents

Environmental impacts associated with the distribution of ethanol include both air and liquid spill emissions. Air emissions occur through exhaust and evaporation. Exhaust emissions include those emissions released from fuel combustion by tank trucks and locomotives used to distribute ethanol. When pipelines are employed to transport ethanol, exhaust emissions are released in the production of electricity which drives the pumps. Exhaust emissions are expected to change between 2000 and 2010 due to improvements in engines and emission control technologies.

Evaporative emissions result from the vaporization and release of VOCs. These emissions occur at all stages of the distribution process: during transit between facilities, during loading and unloading, and during storage. Reductions in the level of evaporative emissions are expected to take place between 2000 and 2010 as a result of improved handling procedures, and reduced evaporative emissions from tank trucks through mandated changes in their Reid Vapor Pressure (RVP).

Liquid spills resulting from normal distribution procedures result in the release of ethanol into surrounding soil and water. Such spills occur during loading and unloading, from leaks in pipes or tanks, and from other accidental discharges. The spill rate is not expected to change over time.

The emissions factors presented are based on a representative distribution system in which all of the ethanol transported is carried by tank trucks and rail cars; pipelines were not included in this representative case. Table III-1 offers estimates of overall weighted emission factors for the ethanol distribution infrastructure in 2000. Table III-2 provides the estimates for the years 2010 through 2030 (which remain constant).[22]

TABLE III-1
OVERALL WEIGHTED EMISSION FACTORS FOR THE ETHANOL DISTRIBUTION INFRASTRUCTURE IN 2000

TRANSPORT INFRASTRUCTURE	Weighted Emission Factors (lbs, tons/MMBtu)							
	Exhaust HC	CO	NO_x	Part	CO_2	SO_2	Evap VOC	Liquid Spills
Ethanol	0.000794	0.00217	0.00891	0.000190	0.821	0.000251	0.00345	0.00146

TABLE III-2
OVERALL WEIGHTED EMISSION FACTORS FOR THE ETHANOL DISTRIBUTION INFRASTRUCTURE IN 2010

TRANSPORT INFRASTRUCTURE	Weighted Emission Factors (lbs, tons/MMBtu)							
	Exhaust HC	CO	NO_x	Part	CO_2	SO_2	Evap VOC	Liquid Spills
Ethanol	0.000625	0.00144	0.00513	0.000117	0.705	0.000216	0.00239	0.00875

c. Direct Resource Requirements

The principal resource requirements for the distribution of ethanol include energy feedstocks and labor. Liquid fuels in the form of ethanol and diesel fuel are used by trucks and locomotives to transport ethanol in tanks, while electricity drives the pumps used to distribute ethanol through pipelines. Human labor is associated with the distribution through all methods. Table III-3 provides estimates for resource requirements per million Btu of ethanol transported.

TABLE III-3
SUMMARY OF TOTAL INPUTS AND OUTPUTS FOR ETHANOL DISTRIBUTION INFRASTRUCTURE IN 2000 AND 2010

	2000	2010
	per MMBtu	per MMBtu
INPUTS		
Ethanol (bbl)	0.315	0.315
No. 2 Diesel Fuel (bbl)	0.000872	0.000749
Electricity (kWh)	4.88	4.88
Labor (persons)	0.000096	0.000096

2. Chemical and Physical Properties of Ethanol Compared to Conventional Fuels

Petroleum-based fuels, such as gasoline and diesel, are complex mixtures of hydrocarbons. Hydrocarbons are composed of carbon and hydrogen atoms. Ethanol, on the other hand, consists of a hydrocarbon in which one atom of hydrogen has been substituted by a hydroxyl group. Physical properties of ethanol are quite different from hydrocarbons due to the presence of the hydroxyl group. There is a strong tendency for alcohol molecules (as in ethanol) to associate with each other through "hydrogen bonds." These differences in chemical and physical characteristics have an important influence on the properties associated with the combustion of ethanol.[23]

a. Chemical Properties of Ethanol Compared to Conventional Fuels

The table below shows the chemical structure of ethanol and its related hydrocarbon ethane, as well as the alkyl group (symbolized by "R"):

TABLE III-4
CHEMICAL STRUCTURE OF ETHANOL

Hydrocarbon Name	Formula	R	Alcohol Formula	Name
Ethane	CH_3CH_3 (C_2H_6)	CH_3CH_2	CH_3CH_2-OH	Ethanol

Gasoline is a complex chemical mixture consisting of volatile hydrocarbons primarily saturates, olefins, aromatics and numerous other additives.[24] Its chemical structure is variable:

$$C_4 \text{ to } C_{12}$$

According to the Auto/Oil Air Quality Improvement Research Program, industry average gasoline has the following chemical characteristics:[25]

TABLE III-5
CHEMICAL CHARACTERISTICS OF AVERAGE GASOLINE

Aromatics:	32%
Olefins:	12%
T_{90}:	335
Sulfur:	300ppm

The 1990 Clean Air Act Amendments (CAAA) stipulate various chemical characteristics for reformulated gasoline for ozone non-attainment areas beginning in 1995:

TABLE III-6
CAAA CHEMICAL CHARACTERISTICS FOR REFORMULATED GASOLINE

Summer Months		Winter Months	
Aromatics:	32%	Aromatics:	26.3%
Olefins:	9.2%	Olefins:	11.9%
T_{90}:	330	T_{90}:	332
Sulfur:	339ppm	Sulfur:	340
Benzene:	1.53%	Benzene:	1.64%

b. Physical Properties of Ethanol Compared to Conventional Fuels

A comparison of the physical properties of ethanol, gasoline and diesel is presented in Table III-7 below:[26]

TABLE III-7
PROPERTIES OF ETHANOL, GASOLINE AND NO. 2 DIESEL FUEL

Property	Ethanol	Gasoline	No. 2 Diesel Fuel
Formula	C_2H_5OH	C_4 to C_{12}	C_8 to C_{25}
Molecular weight	46.07	100-105	200 (approx.)
Composition, weight %			
Carbon	52.2	85-88	84-87
Hydrogen	13.1	12-15	13-16
Oxygen	34.7	0	0
Specific gravity, 60°F/60°F	0.794	0.72-0.78	0.81-0.89
Density, lb/gal @60°F	6.61	6.0-6.5	6.7-7.4
Boiling temperature, °F	172	80-437	370-650
Reid vapor pressure, psi	2.3	8-15	<0.2
Octane no. (see note 1)			
Research octane no.	106	88-98	---
Motor octane no.	89	80-88	---
Cetane no. (see note 1)	8	14	40-55
Water solubility, @70°F			
Fuel in water, volume %	100	Negligible	Negligible
Water in fuel, volume %	100	Negligible	Negligible
Freezing point, °F	-173.2	-10	-10-30
Refractive index, n_D @68°F	1.3614	1.4-1.5	1.4-1.5
Viscosity			
Centipoise @68°F	1.19	0.37-0.44	2.6-4.1
Centipoise @-4°F	2.84	0.60-0.77	9.7-17.6
Coefficient of expansion, @60°F 1 atmosphere, per °F	0.00062	0.00067	0.00046
Electrical conductivity, mhos/cm	1.35×10^{9}	1×10^{14}	1×10^{12}
Flash point, closed cup, °F	55	-15	165
Autoignition temperature, °F	793	495	600 (approx.)

TABLE III-7
PROPERTIES OF ETHANOL, GASOLINE AND NO. 2 DIESEL FUEL
(CONTINUED)

Flammability limits, volume % Lower Higher	 4.3 19.0	 1.4 7.6	 1.0 6.0
Latent heat of vaporization Btu/gal @60°F Btu/lb @60°F Btu/lb air for stoichiometric mixture @ 60°F	 2,378 396 44.0	 900 (approx.) 150 (approx.) 10 (approx.)	 710 (approx.) 100 (approx.) 8 (approx.)
Heating value (see note 2) Higher (liquid fuel-liquid water) Btu/lb Lower (liquid fuel-water vapor) Btu/lb Lower (liquid fuel-water vapor) Btu/gal @60°F Gaseous fuel-water vapor Btu/lb @60°F	 12,800 11,500 76,000 11,900	 18,800-20,400 18,000-19,000 109,000-119,000 19,000-19,300	 19,200-20,000 18,000-19,000 126,000-130,800 ---
Heating, value, stoichiometric mixture Mixture in vapor state, But/cubic foot @68°F Fuel in liquid state, Btu/lb of air	 94.7 1,280	 95.2 1,290	 96.9 ---
Specific heat, Btu/lb-°F	0.57	0.48	0.43
Stoichiometric air/fuel, weight	9.00	14.7	14.7
Volume % fuel in vaporized stoichiometric mixture	6.5	2.0	---
Ratio moles product/moles charge	1.07	1.05	1.06
Ratio moles product/moles $O_2 + N_2$	1.12	1.08	1.07

1. Laboratory engine Research and Motor octane rating procedures are not suitable for use with neat oxygenates. Octane values obtained by these methods are not useful in determining knock-limited compression ratios for vehicles operating on neat oxygenates and do not represent octane performance of oxygenates when blended with hydrocarbons. Similar problems exist for cetane rating procedures.
2. The higher value is cited for completeness only. Since no vehicles in use, or currently being developed for future use, have powerplants capable of condensing the moisture of combustion, the lower heating value should be used for practical comparisons between fuels.

3. Engine Efficiencies with Ethanol and Conventional Fuels

The capacity of a vehicle's engine to convert liquid fuels into miles travelled (i.e., fuel economy) is based largely on two factors: the optimization of the vehicle to operate on the particular fuel, and the heating value of the fuel itself. The heating value of ethanol is lower than that of gasoline. This has a negative impact on fuel economy. The heating values for ethanol and conventional gasoline follow in the table below:

TABLE III-8
HEATING VALUES FOR ETHANOL AND GASOLINE

Heating Value	Ethanol	Gasoline
Btu/lb	11,500	18,000-19,000
Btu/gal at 60°F	76,000	109,000-119,000

The impacts on fuel economy are projected by the Energy Information Administration. This data presented in Table III-9, below, illustrates the various achievable mileage efficiencies in terms of miles per gallon. Note that improved mileage is due to improvements in vehicle optimization to the various fuels.

TABLE III-9
ACHIEVABLE NEW-CAR MILEAGE EFFICIENCIES
(MILES PER GALLON)

Fuel/Vehicle	1990	1995	2000	2005	2010
Conventional Gasoline	28.2	30.1	32.1	34.4	37.1
Reformulated Gasoline		28.9	30.8	33.0	35.6
E10, Reformulated Gasoline		28.3	30.2	32.3	
E85, Flexible Fuel Vehicle		22.5	24.0	25.7	
E95, Dedicated Vehicle				26.2	28.3

Fuel efficiency is measured thermally instead of volumetrically. Whereas ethanol has a lower energy density, it is more thermodynamically efficient than gasoline. This comparison is made in miles traveled per unit of energy consumed (typically Btus/mile).[27] Table III-10 depicts the different mileage efficiencies achievable for various fuels/vehicle combinations in miles per million Btu. The E10 fuel economy figures are based on increased volume of combustion products and on the effects of charge air cooling. The result is a 1 - 2% net increase in miles per Btu. The E85 fuel economy figures are based on efficiencies gained in charge air cooling and increased exhaust volume. The flexible fuel vehicle cannot take advantage of increased compression ratios which is a benefit available to dedicated vehicles. The E95 fuel economy figures are based on the use of a dedicated vehicle and are derived from a 7% efficiency gain due to increases in exhaust product volume, charge air cooling and compression ratio.

TABLE III-10
ACHIEVABLE NEW-CAR MILEAGE EFFICIENCIES
(MILES PER MILLION BTU)

Fuel/Vehicle	1990	1995	2000	2005	2010
Conventional Gasoline	245	262	279	299	323
Reformulated Gasoline		262	279	299	323
E10, Reformulated Gasoline		266	282	303	
E85, Flexible Fuel Vehicle		276	294	315	
E95, Dedicated Vehicle				337	364

4. Emissions from Ethanol and Gasoline

One of the fundamental justifications for using ethanol is the potential reduction in harmful emissions associated with vehicular travel. New government regulations are a significant driving force behind the search for cleaner fuels. Regulations, such as the 1990 Clean Air Act Amendments, are fostering the market for ethanol as fuel suppliers and vehicle manufacturers strive to achieve the mandated emissions regulations.

There are two principal air pollution problems to which vehicle emissions contribute. One problem is that of carbon monoxide accumulations. Research has demonstrated that the release of carbon monoxide through exhaust emissions is greatest when the combustion process of the vehicle's engine is less than complete. This occurs most commonly in the winter or colder months when engines operate less efficiently. It has been found, however, that the addition of oxygen to the fuel increases the combustion efficiency. Ethanol is one of the major additives used to oxygenate the gasoline.

The formation of urban ozone, or smog, is the other principal air pollution problem of concern relating to emissions from the transportation sector. Reformulated gasoline is intended to reduce ozone precursors by lowering the emissions of toxics and VOCs. This is achieved by reducing the following factors or components of the fuel: aromatics, olefins, Reid Vapor Pressure (RVP), sulfur, and by adding 2% weight oxygen to the fuel. Once again, ethanol can play a role in this emissions reduction strategy. However, the net impact of ethanol's use in low level blends is unclear given its potential to increase the RVP. Table III-11 outlines the principal emissions from gasoline, reformulated gasoline, and ethanol blends with conventional and reformulated gasoline.

TABLE III-11
EMISSIONS FROM ETHANOL AND CONVENTIONALLY FUELED ENGINES

Fuel/Pollutant	Units	1990	2000	2010
Gasoline, 8 psi RVP				
Exhaust VOC	grams/mile	0.27	0.28	0.28
CO	grams/mile	2.81	2.91	2.91
NO_x	grams/mile	0.64	0.63	0.63
CO_2	grams/mile	317	278	241
SO_2	mg/mile	70	61	53
Benzene	mg/mile	1.7	1.7	1.7
1-3 Butadiene	mg/mile	0.13	0.13	0.13
Formaldehyde	mg/mile	0.27	0.27	0.27
Acetaldehyde	mg/mile	0.19	0.19	0.19
Reformulated Gasoline, 6.7 psi RVP				
Exhaust VOC	grams/mile		0.21	0.21
CO	grams/mile		2.19	2.19
NO_x	grams/mile		0.63	0.63
CO_2	grams/mile		280	243
SO_2	mg/mile		52	45
Benzene	mg/mile		0.79	0.79
1-3 Butadiene	mg/mile		0.10	0.10
Formaldehyde	mg/mile		0.20	0.20
Acetaldehyde	mg/mile		0.14	0.14
E10, Splash Blended, 8.1 psi RVP				
Exhaust VOC	grams/mile	0.26	0.18	
CO	grams/mile	2.53	2.09	
NO_x	grams/mile	0.68	0.4	
CO_2	grams/mile	314	278	
SO_2	mg/mile	64	50	
Benzene	mg/mile	1.53	0.86	
1-3 Butadiene	mg/mile	0.12	0.11	
Formaldehyde	mg/mile	0.54	0.48	
Acetaldehyde	mg/mile	0.47	0.42	

TABLE III-11
EMISSIONS FROM ETHANOL AND CONVENTIONALLY FUELED ENGINES
(CONTINUED)

E10, RVP Adjusted, 6-7 psi RVP			
Exhaust VOC	grams/mile	0.19	0.09
CO	grams/mile	2.09	1.70
NO_x	grams/mile	0.4	0.2
CO_2	grams/mile	278	241
SO_2	mg/mile	50	43
Benzene	mg/mile	0.86	0.42
1-3 Butadiene	mg/mile	0.11	0.05
Formaldehyde	mg/mile	0.48	0.24
Acetaldehyde	mg/mile	0.42	0.21
E95, 3.5 psi RVP			
Exhaust VOC	grams/mile	0.18	0.09
CO	grams/mile	2.09	1.70
NO_x	grams/mile	0.4	0.2
CO_2	grams/mile	2.59	209
SO_2	mg/mile	4.2	3.5
Benzene	mg/mile	0.34	0.17
1-3 Butadiene	mg/mile	0.04	0.02
Formaldehyde	mg/mile	0.36	0.18
Acetaldehyde	mg/mile	1.02	0.51

A relatively new fuel additive, ethyl tertiary butyl ether (ETBE), which is produced by a catalytic reaction between isobutylene and ethanol, has the potential to address both the carbon monoxide emissions problems and the release of ozone precursors, without increasing the RVP of the fuel. Emissions data for ETBE are limited currently, but results from the Auto/Oil study as depicted in Table III-12, show the impacts of adding ETBE to conventional gasoline. Results from exhaust emissions are clearly beneficial, whereas there testing on evaporative emissions was not statistically significant.

TABLE III-12
VEHICLE EXHAUST EMISSIONS EFFECTS FROM ADDING ETBE CURRENT VEHICLE FLEET, (PERCENT CHANGE)

Exhaust (Based on gm/Test)	ETBE (0% -> 10%)
Total HC	-5.2 ± 3.7
NMHC	-6.3 ± 3.9
CO	-14.6 ± 7.4
NO_x	5.5 ± 6.3
Benzene	-9.5 ± 8.2
1,3-Butadiene	-2.6 ± 8.6
Formaldehyde	17.1 ± 71.8
Acetaldehyde	256.6 ± 67.9

5. Comparison of Emission Regulations

As mentioned earlier, new government regulations are a major driving force behind the use of ethanol in achieving emission decreases for light duty vehicles. Regulations, such as the CAAA of 1990, will propel developments in vehicle technology using fuels cleaner than conventional gasoline, such as ethanol. These regulations also foster development of markets for ethanol, as fuel suppliers and vehicle manufacturers strive to achieve the mandated emission reductions.

Table III-13 compares the CAAA emission standards for vehicles using reformulated gasoline (effective 1995) with vehicles using alternative fuels, such as ethanol (effective 2003).

The CAAA extend the focus of emission control from engine technologies to the fuels themselves. The oxygenated fuels program seeks to reduce CO emissions by mandating that during certain periods gasoline should have 2.7% oxygen content in all CO nonattainment areas, beginning November 1, 1992. (A nonattainment area is one in which designated emission levels are above National Ambient Air Quality Standards established by EPA.) The CAAA also use fuel content strategies to control the emissions of ozone precursors. The amendments mandate the reformulation of gasoline to 2.0% oxygen for year-round use in the nine ozone nonattainment areas beginning in 1995. Ethanol may play a key role in these programs due to the fact that simply adding it to gasoline can elevate the oxygen level without requiring engine or infrastructure modification. Table III-14 lists the CO nonattainment areas and the periods in which they must use oxygenated fuels. The ozone nonattainment areas are listed, along with states that may choose to "opt-in" to the program, in Table III-15.

TABLE III-13
COMPARISON OF 1990 CLEAN AIR ACT LIGHT DUTY VEHICLE EMISSION STANDARDS

	Regular Vehicles 1995		Regular Vehicles 2003(1)	Clean Fuel Vehicles 1996		Clean Fuel Vehicles 2001	
	50,000 Miles	100,000 Miles		50,000 Miles	100,000 Miles	50,000 Miles	100,000 Miles
Exhaust VOCs	.25	.31	.125	.125	.156	.075	.090
CO	3.4	4.2	1.7	3.4	4.2	3.4	4.2
NOx	0.4	0.6	0.2	0.4	0.6	0.2	0.3
Formaldehyde(2)				.015	.018	.015	.018

(1) To be imposed at descretion of EPA Administrator if deemed necessary according to research conducted by OTA and EPA.

(2) The regular vehicle standards regulate formaldehyde, as well as other toxic emissions such as benzene, 1,3 butadiene, acetaldehyde and polycyclic organic matter in terms of aggregate emissions. In 1995, the Act mandates 15% reduction from the baseline gasoline on the aggregate emissions of each of these toxics. In 2000, a 25% reduction from the baseline gasoline is mandated, (although this may be adjusted to 20% by the EPA Administrator).

TABLE III-14
CAAA OXYGENATED FUELS PROGRAM

Control Area	Control Period	Control Area	Control Period
Baltimore	11/1 -2/29	New York/No. NJ	All year
Boston		Duluth	10/1 - 1/31
Greensboro		Fresno	
Hartford		Minneapolis	
Philadelphia		Chico	
Raleigh		Modesto	
Syracuse		Reno	
Washington, DC		Sacramento	
Cleveland		San Francisco	
Memphis		Stockton	
Albuquerque		Grant's Pass, OR	
El Paso		Klamath Co., OR	
Colorado Springs		Medford	
Denver/Boulder			
Fort Collins		Las Vegas	
Missoula		Phoenix	10/1 - 2/29
Provo/Orem			
Anchorage		Los Angeles	
Fairbanks		Spokane	9/1 - 2/29
Portland, OR			
Seattle			
San Diego			

TABLE III-15
CAAA REFORMULATED FUELS PROGRAM
(9 OZONE AREAS AND OPT-INS AS OF 4/92)

Original 9 Nonattainment Areas	"Opt-In" States
Baltimore	Connecticut
Chicago	Delaware
Hartford	Maine
Houston	Maryland
Los Angeles	New Hampshire
Milwaukee	New Jersey
New York City	New York
Philadelphia	Rhode Island
San Diego	Virginia

6. Ethanol Cost Indicators

The cost of producing ethanol has declined substantially in the past 12 years. In 1980, a gallon of ethanol cost approximately \$3.60. Improvements in fermentation and conversion processes have lowered that to a current cost of approximately \$1.30 per gallon. The Department of Energy (DOE) has established aggressive goals for lowering the cost of ethanol through improvements in the manufacturing process and in the types of feedstock to be used. Research is planned in the key component areas of ethanol production, including: improved cellulose conversion, improved pretreatment, improved hemicellulose conversion, and enhanced feedstock collection and production.

By reducing the cost of manufacturing ethanol, it is expected that the wholesale price per gallon of ethanol will fall to approximately \$0.67 (1987 dollars) by the year 2000. This price is equivalent to \$0.80-\$1.00 per gallon of gasoline. It is expected that this price can be sustained without government subsidies.

If successful in achieving these cost reductions by 2000, DOE projects that ethanol will remain competitive with gasoline through 2030 and will displace 6.29 million barrels/day of gasoline by that year. Table III-16 illustrates the ethanol production levels which are expected:

TABLE III-16
ETHANOL PRODUCTION LEVELS

Year	Biomass Million Dry Tons/Year	Ethanol Billion Gallons/Year	Gasoline Displaced Million Barrels/Day
2000	116.6	12.8	0.65
2010	361.2	39.7	2.01
2020	616.3	67.8	3.44
2030	1126.1	123.9	6.29

ENDNOTES:

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27. Tshiteya, Rene et al., Op Cit., 1991.